Appendix IV
Channel Construction Design Document

LOWER CLEAR CREEK
FLOODWAY REHABILITATION PROJECT

Channel Reconstruction, Riparian Vegetation, and Wetland Creation Design Document

Prepared for:

Clear Creek Restoration Team

Contemporary peer reviewers

Future project evaluators

Prepared by:

McBain and Trush
P.O. Box 663
Arcata, CA 95518

Graham Matthews
P.O. Box 1516
Weaverville, CA 96093

North State Resources
5000 Bechelli Lane, Suite 203
Redding, CA 96002

30 August 2000

This page intentionally left blank

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Lower Clear Creek Floodway Rehabilitation Project will rehabilitate two degraded reaches of Clear Creek (Figures 1 and 2): a 1.9 mile reach (Project Reach) extensively mined for aggregate and a 1.0 mile reach (Reading Bar Reach) containing dredger tailings to be used as borrow materials at the Project Reach. In addition, two off-channel sites (Gallery and Old Mill borrow sites) will be restored as wetland/riparian habitat following removal of borrow materials for the Project Reach. This document will present quantitative rehabilitation objectives, an approach to achieve these objectives, and design procedures for Phases 2-4 of the lower Clear Creek rehabilitation project.

At the Project Reach, extensive in-channel and floodplain aggregate extraction removed natural channel confinement, natural point bars, floodplains, and riparian vegetation, leaving an unconfined floodway with multiple low-flow channels and numerous large pits. The pits and lack of a defined channel strand adult salmonids returning from the ocean to spawn and juvenile salmonids emigrating to the ocean. The Reading Bar Reach, also placer mined and dredged for gold in the 19th and early 20th century, has a severely damaged channel morphology.

The Project Reach is the only section of lower Clear Creek that has been extensively mined for instream aggregates. The resulting degraded channel morphology is a significant stressor to anadromous salmonid production in lower Clear Creek, including spring-run, fall-run, and late fall-run chinook salmon (*Oncorhynchus tshawytscha*), and steelhead (*Oncorhynchus mykiss*). This high priority rehabilitation activity has been identified in numerous restoration documents, including the Lower Clear Creek Watershed Analysis (BLM/RCD 1995), AFRP Working Paper (USFWS 1995), and CALFED Strategic Plan (1999).

This project will not only benefit salmonids; the project will rehabilitate form, function, and structure for the Clear Creek channel and the adjoining floodplain, native flora and fauna should benefit as well. For example, as restored patches of cottonwoods mature, cavity nesting birds will begin utilizing these patches. A variety of native species will utilize early successional willow patches created within a dynamic channel morphology. The floodway design presented below is a work in progress; the channel location and dimensions are based on our current understanding of how the system works. As we gain more geomorphic information and improve our revegetation implementation methods, we expect the channel design to evolve as we incorporate these improvements.

2. BACKGROUND

River channel restoration is a relatively recent and rapidly expanding field. The recent literature documents many ecologically-based channel and wetland restoration projects, almost all completed since the early 1980s. Many of these projects, particularly those in Europe, have involved restoration of natural meanders in a channelized reach (Binder et al. 1983, Brookes 1987, Jungwirth et al. 1995, Toth 1996, Brookes and Shields 1996, Olsen 1996). Recent projects in the United States that attempt to restore natural function include the Blanco River in Colorado, Greenhorn Creek in Plumas County, California, the Wood River in Klamath County, Oregon, the Kissimmee and St. Johns Rivers in Florida, and many others.

Many of these restoration projects are in lowland areas with low stream gradients, where historical information indicates a sinuous, meandering channel existed prior to straightening and channelization. Some projects have been implemented after catastrophic floods, where restoration actions were intended to jumpstart the natural recovery process. Other projects attempt to either stabilize the stream (bank protection, grade control structures) or assume that it is a static system. These projects often fail to accommodate the naturally dynamic nature of the river. Lower Clear Creek is blessed because most of the lower corridor is under public ownership, therefore the need to protect structures (homes, bridges) from flood damage is virtually non-existent. This project offers the rare opportunity to design and encourage a dynamic channel, one that not only transports coarse sediment, but one that can freely migrate between valley walls. This ability is incorporated into our rehabilitation approach and objectives.

3. HISTORICAL EVOLUTION OF LOWER CLEAR CREEK

Beginning with the discovery of gold at Reading Bar in 1848, lower Clear Creek has undergone significant changes due to land use. Various forms of gold mining transformed the natural landscape into piles of placer, hydraulic, and dredger tailings. In most locations, the entire floodway was “turned upside down” in the search for gold. Gold mining also brought secondary impacts to the creek, including roadbuilding, deforestation, and urban development. Dredger tailings adjacent to the creek between Saeltzer Dam and Clear Creek Bridge are the most pronounced relics of historic gold mining activity, with the tailings confining the river and providing very little value as floodplain or riparian habitat. Saeltzer Dam was constructed in the early 1900’s for diverting irrigation water, which also blocked upstream access by migrating salmonids and trapped coarse sediment from upstream sources.

The next significant impact to lower Clear Creek was the Trinity River Division of the Central Valley Project. Completed in 1963, Whiskeytown Dam and reservoir trapped coarse sediment, but more importantly, greatly reduced the volume and magnitude of historic flows. Reducing the magnitude and frequency of high flow events responsible for creating and maintaining lower Clear Creek allowed fine sediment to accumulate in the channel and allowed riparian vegetation to establish and mature along the low flow channel. As the vegetation matured, the combined root strength of the riparian band “fossilized” gravel deposits and reduced the quantity and quality of aquatic habitat. Salmonids, aquatic invertebrates, and other aquatic species are more productive if gravel deposits have fewer fine sediments (e.g., fine sediment in salmon spawning gravels reduces egg-to-emergence survival by reducing oxygen delivery and metabolic waste removal).

The last significant impact to lower Clear Creek was instream and off-channel gravel mining, occurring from 1950 to 1978. In the short reach where instream mining occurred (from river mile 2.2 to 3.8), several hundred thousand cubic yards were removed from the floodway. Impacts to channel morphology and salmonid habitat were significant; the bankfull channel was destroyed and floodplains removed, leaving wide shallow channels and interspersed deep pits. Destroyed channel morphology reduced sediment routing through the reach. Excessive gravel removal exposed a clay hardpan over much of the channel bottom, directly removing salmonid spawning and fry rearing habitat. Salmon and steelhead spawn in gravel and cannot spawn on clay hardpan. Equally important was the lost channel confinement, allowing both adult and juvenile salmonids to stray into adjacent pits and be stranded.

The cumulative impacts of these land uses are summarized as follows:

1. <u>Simplification of channel morphology.</u> Comparing 1937 and 1997 channel locations shows a distinct trend of channel straightening, which has resulted in fewer and shallower pools, and longer riffles (Figure 3).
2. <u>Downcutting of channel.</u> Gravel extraction and upstream blockage of coarse sediment supply has caused Clear Creek to downcut to the clay hardpan in many locations, particularly at the proposed rehabilitation site. Low flow water surface profiles in 1937 and 1997 show local downcutting over 5 feet (Figure 4). This process has converted much of the channelbed surface from gravels and cobbles to exposed clay hardpan. Exposed cobbles and gravels characteristic of a low gradient alluvial channel provides high quality aquatic habitat; loss of gravels and cobbles, and conversion to exposed clay hardpan, greatly reduces salmonid spawning and fry rearing habitat.
3. <u>Loss of a defined bankfull channel and floodplain.</u> Gravel extraction physically removed any semblance of a defined bankfull channel and floodplain, leaving the stream with deep pits and multiple low-flow channels. Figure 5 and 6 shows sequential aerial photographs for (a) the upstream end of the project reach and (b) the middle of the project reach for the years 1952, 1963, 1981, and 1984. Similar views in 1997 are shown in Figure 7. Photos from 1952 and 1963 document a significantly different channel from the post-dam and instream mining time period. The 1963 photo shows a channel recently exposed to the Dec 1955 and Feb 1958 floods (about 40-year and 15-year events, respectively). These historical photos show wide expanses of exposed gravels and cobbles, with riparian vegetation as patches associated with high flow scour channels and floodplains. The 1981 and 1984 photos illustrate the impact of gravel extraction in the project reach, and the response of the 1983 flood to the gravel extraction reach. The 1997 photo shows pre-rehabilitation project conditions; the only difference between the 1997 photo and current conditions is implementation of Phase 1 of this project in the fall of 1998, isolating the southern pond in the upper image of Figure 7.

This project seeks to reverse these negative impacts by reconstructing a properly sized channel morphology in lower Clear Creek, as well as improving habitat in adjacent sites that will provide construction materials for the instream portion of the project. Proper design of the instream portion of the project requires a more thorough evaluation of primary factors that create and maintain channel morphology. Much of this evaluation has been performed in several technical memoranda previously prepared by the design team, as well as substantial new analyses. These reports include:

(1) Lower Clear Creek hydrologic evaluation technical memorandum (April 1998)
(2) Lower Clear Creek bedload transport measurements-technical memorandum for WY 1998 (May 1999)
(3) Lower Clear Creek Floodway Rehabilitation Project – Specifications package for Phase One design(May 1998)
(4) Lower Clear Creek Floodway Rehabilitation Project – CALFED Grant Application for Phase 2-4 (July 1998)
(5) Lower Clear Creek Floodway Rehabilitation Project – Conceptual rehabilitation plan (May 1999)

Information contained in these reports and documents is only summarized as necessary rather than repeated. If the reader wishes to obtain these documents from the Clear Creek Restoration Team, please contact Mr. Jim Destaso, US Bureau of Reclamation, 16349 Shasta Dam Blvd, Shasta Lake, CA 96019.

4. SITE DESCRIPTION

Clear Creek originates in the Trinity Mountains, and flows south between the Trinity River basin to the west and the Sacramento River basin to the east, and ranges from over 6,000 ft elevation at Shasta Bally to 400 ft elevation as it joins the Sacramento River. The lower section of Clear Creek flows south from Whiskeytown Dam for approximately 8 miles, then flows east for 8 miles before joining the Sacramento River five miles south of Redding. The primary gaging station on Clear Creek is 8 miles downstream of Whiskeytown Dam (Clear Creek near Igo), with a drainage area of 228 mi^2. The unregulated drainage area between Whiskeytown Dam and the confluence with the Sacramento River is 48.9 mi^2.

Clear Creek is part of the Trinity River Division of the Central Valley Project, and streamflows have been regulated by Whiskeytown Dam since May 1963. Trans-basin diversion from the Trinity River through Judge Francis Carr power plant to Whiskeytown Lake began in April 1963. Diversions from Whiskeytown Lake to the Sacramento River via Spring Creek tunnel into Keswick Reservoir began in December 1963.

The climate in the Clear Creek watershed is Mediterranean, with most precipitation occurring in the winter months (November through April) and dry summers with temperatures exceeding 100 degrees Fahrenheit. Average annual precipitation in the Clear Creek watershed varies from 20 inches near the confluence with the Sacramento River to over 60 inches in the upper watershed. Precipitation is primarily rainfall, with snow occurring at the highest elevations of the watershed.

As introduced in the previous section, there are several damaged reaches of lower Clear Creek, the primary being the instream gravel mining reach from river mile 2.2 to 3.8. Instream gravel mining removed much of the gravel from the floodway in this reach, leaving large instream pits and a wide, shallow floodway. Rehabilitation will require substantial fill to recreate a defined channel and floodplain. Fill material will be borrowed from two upstream sites: Reading Bar and the Former Shooting Gallery (Gallery), (Figure 2). The benefit of using local borrow sites is that fill can be removed in a way to restore borrow sites as well as the project site; in effect, restoring four sites for the price of one. Each site has unique project components and rehabilitation objectives, which are listed below:

Project site: Rehabilitate 1.5 miles of Lower Clear Creek from river mile 2.2 to 3.8, including reconstructing the bankfull channel, reconstructing the floodplain by filling in mining pits, and planting riparian vegetation on reconstructed floodplain surfaces. Primary design issues are channel geometry, planform geometry, riparian revegetation, integrating riparian revegetation into topographic design, and integrating aquatic habitat needs into topographic design. Four phases are identified, with Phase 1 completed in Fall 1998, Phase 2 commencing in Fall 1999, and Phase 3 and 4 completed after 2001. Phase 1 and 2 focus on filling mining pits and recreating floodplains, while Phase 3 and 4 focus on channel relocation and reconstruction.

Reading Bar: Primary borrow site to implement Phase 2 at the Project Reach. As dredger tailings are removed, the left bank of lower Clear Creek will be returned a functional floodplain from river mile 7.8 to 8.4, and a small wetland outside of the contemporary floodway will be created. The floodplain will be planted with native riparian vegetation, and the off-channel wetland will be planted with native emergent vegetation.

Former Shooting Gallery (Gallery): Primary borrow site to implement Phase 3 and 4 at the Project Reach. As dredger tailings are removed, the former shooting range will be converted to a complex off-channel wetland complex. Portions of the off-channel wetland will be planted with native emergent wetland vegetation to evaluate natural vegetation recruitment success versus planted wetland vegetation efforts. Dredger tailings in the gulch area will be removed down to an elevation near the winter groundwater table and replanted with native riparian vegetation.

5. REHABILITATION APPROACH AND OBJECTIVES

The goal of the Lower Clear Creek Floodway Rehabilitation Project is to rehabilitate the natural form and function of the channel and floodplain, which includes increasing riparian vegetation, increasing the quantity and quality of salmonid habitat, and increasing the quantity and quality of terrestrial riparian habitats. To achieve these goals, the project will reconstruct selected reaches of the lower Clear Creek channel, improve fish passage, spawning, and rearing habitat, extensively plant riparian vegetation, and create off-channel wetlands for waterfowl and other wetland species. This project is being planned within the context of watershed-level rehabilitation and management planning under the Lower Clear Creek Coordinated Resource Management Program (CRMP). Other significant CRMP projects include removing or modifying Saeltzer Dam, introducing spawning gravels into lower Clear Creek, implementing erosion control programs, and reducing fuels within the watershed. Funding for the project comes from several sources, and the objectives of those funding sources are described below.

5.1. FUNDING SOURCES AND THEIR OBJECTIVES

Project planning and implementation are being funded by the Central Valley Project Improvement Act (CVPIA) and the CALFED Bay Delta Ecosystem Restoration Program. Funding for off-channel wetland creation is also being provided by the BLM Abandoned Mines program. Total funding for this project will require approximately $14,000,000. Clear Creek is a specific line item restoration stream in the CVPIA, with a primary purpose to protect, restore and enhance fish, wildlife and associated habitats in the Central Valley and Trinity River Basins of California. The largest funding contributor to this project is the CALFED Bay Delta Ecosystem Restoration Program. CALFED's primary ecosystem restoration objective is to:

"Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species"

The objective to "improve ecological function" is difficult to quantify. We attempt to better describe this goal as "attributes of alluvial river integrity" that help guide rehabilitation goals and objectives of this project.

5.2. ALLUVIAL RIVER ATTRIBUTES AS A GUIDE TO REHABILITATION

Our approach to channel rehabilitation design is based on a series of alluvial attributes that have been found to effectively define the geomorphic characteristics of a healthy, fully functioning river system (McBain & Trush 1997). The term "alluvial" exceeds simply having the channel composed of cobbles and gravels (alluvium); the river must also be able to form and adjust its bed and banks. We define these alluvial attributes for each system based on site-specific characteristics, and then develop the linkages between these attributes that will encourage a dynamic, self-sustaining river ecosystem to the greatest extent possible within contemporary constraints (dams, structures in the floodway). In the following sections, we review the attributes, explain relationships between existing site conditions and the desired attribute, and finally describe changes that must occur to re-create these functional attributes.

5.2.1. Attribute 1: A spatially complex channel morphology

The historical channel morphology of lower Clear Creek was highly dynamic, with exposed gravel/cobble point bars, high flow scour channels, abandoned main channels, and vegetated floodplains (Figure 8). Historically, the reach of Clear Creek through the project site is between meandering and braided morphology (Figures 5, 6, and 9). Through series landscape perturbations (gold mining, gravel extraction, and dam building), this historical channel morphology was drastically altered. The existing channel morphology of lower Clear Creek within the project area is highly disturbed through a combination of years of gravel extraction and a lack of upstream sediment supply due to upstream dams. These activities resulted in an entrenched channel, confined by dense riparian berms, with a streambed incised to clay hardpan at many locations. The channel has straightened as a result of the incision and developed a rectangular channel geometry typical of highly regulated gravel bedded rivers in California (Kondolf and Matthews, 1993, Williams and Wolman, 1984). The channel morphology has little planform or cross section complexity, and pools are separated by steep, clay hardpan controlled riffles. Where the channel was gravel mined, the bankfull channel and floodplain confinement was eliminated by extraction (Figure 10). In these areas, the channel is multi-channeled, making adult and juvenile salmonid migration difficult. In areas not mined for gravel, channel incision and entrenchment has also greatly reduced the extent of floodplains accessible by contemporary floods, limiting overbank flow and therefore concentrating stream power in the active channel. Lack of functional floodplains and reduced flows have also reduced riparian regeneration on elevated surfaces.

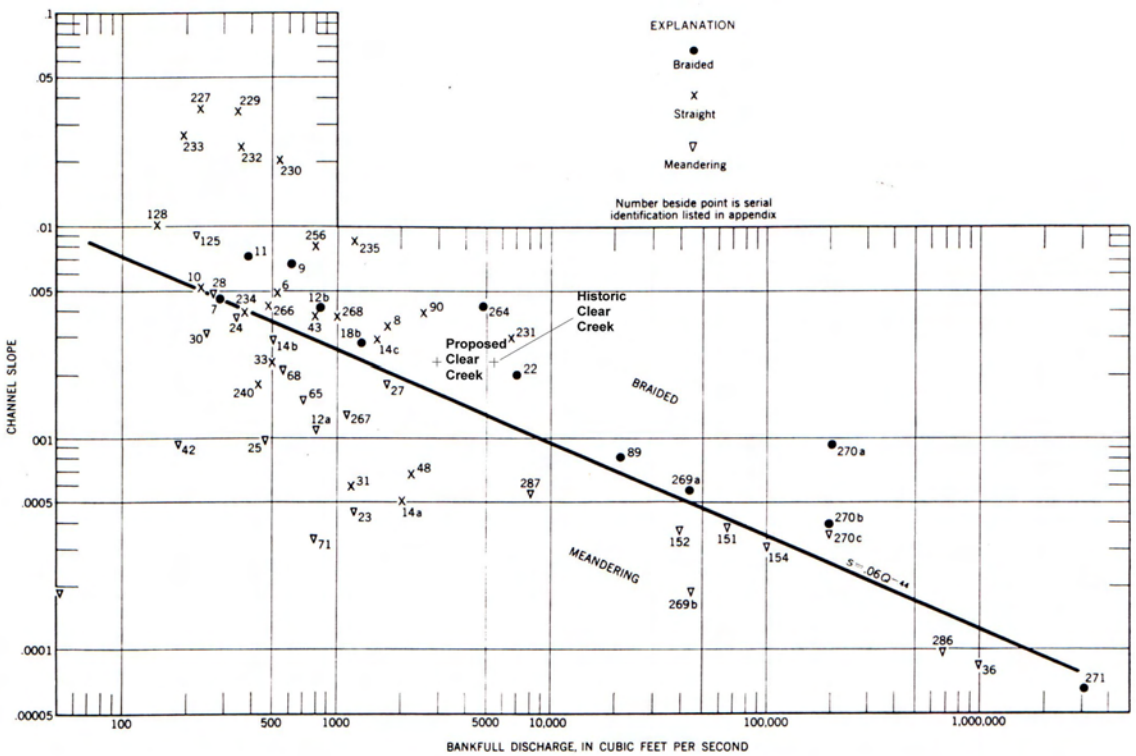

Figure 9. Relationship between braided and meandering channel form, predicting Clear Creek in the transition between meandering and braided channel morphology.

To recreate a spatially complex channel morphology, the streambed must be raised above the clay hardpan horizon, the pits filled as part of reconstructing a bankfull channel and floodplains scaled to the anticipated future high flow regime, and the high flow regime improved to recreate a dynamic, meandering pattern.

5.2.2. Attribute 2: A variable streamflow regime

Long-term success of rehabilitation efforts on lower Clear Creek to restore a dynamic stream channel and floodplain will depend on the nature of the streamflow regime and the amount of coarse sediment added to the system. Unregulated streamflows on Clear Creek were highly variable, with summer baseflows less than 50 cfs and winter peak floods sometimes over 24,000 cfs (Figure 11). Whiskeytown Dam maintained a nearly constant flow of 50 cfs over most of the year, with the exception of small runoff events from the watershed downstream of the dam (Figure 11). Maintaining constant low flows typical of regulated streams tends to cause riparian encroachment and gravel bar fossilization, followed by channel incision and development of a relatively uniform rectangular channel form. This type of channel lacks the complexity needed for high quality aquatic habitat. This pattern is well established on a variety of river channels, including the Trinity River (McBain & Trush, 1997) and is pronounced on Clear Creek as well (Pelzman, 1973). Increasing flow variability via increasing the frequency of high flows greater than 3,000 cfs will be an important factor for the success of this rehabilitation design, as these high flows will discourage future riparian encroachment and encourage a dynamic channel. Presently, Reclamation is evaluating structural and operational alternatives to increase the magnitude and frequency of high flows from Whiskeytown Dam, which should be incorporated into the final design.

5.2.3. Attribute 3: A frequently mobilized channelbed surface

A frequently mobilized bed surface is an important threshold that defines a "dynamic" stream channel. Bed mobilization begins gravel transport, ensures significant fine sediment transport, creates alluvial deposits (riffles and bars) that shape aquatic and terrestrial habitat, and discourages fossilization of exposed bars by riparian vegetation. In healthy rivers, the bed surface is mobilized by flows at or slightly smaller than bankfull discharge, such that the size of the bed surface is indicative of flows that dominate channel dimensions.

The project has two inter-related design approaches to incorporate this attribute: (1) channelbed mobility analysis to design the bankfull channel morphology such that the bed is mobilized by the anticipated bankfull discharge, and (2) decrease the size of the fill material substrate size distribution to ensure mobilization following project channel reconstruction (scale substrate to anticipated future bankfull discharge). Design of the channel substrate will incorporate a particle size distribution that is anticipated to be mobilized by the future 1.5 to 2.0 year flood.

5.2.4. Attribute 4: Periodic scour and redeposition of the channelbed subsurface

Alternate bars, pool tails, and other deposits are scoured deeper than their coarse surface layers by floods exceeding 3-yr to 5-yr annual maximum flood recurrences, followed by re-deposition during the receding limb of the flood hydrograph, such that net change in topography is usually small. Prior to Whiskeytown Dam, periodic high flow events, capable of inducing considerable scour and re-deposition within a single storm hydrograph, maintained a dynamic alternate bar morphology. Bed scour maintained open and exposed gravel bar surfaces by scouring riparian seedlings established during the previous spring/summer. Bed scour greater than the depth of one D_{84} of the coarse surface layer was usually caused by floods exceeding a 3-yr to 5-yr recurrence interval.

Improving this attribute requires two factors: adequate flood flows, and adequately sized channelbed material in sufficient quantities. The relatively small storage of Whiskeytown Dam allows larger spillway events to occur (up to 15,000 cfs). This causes bed scour, but coarse sediment lost behind Whiskeytown and Saeltzer Dams reduces redeposition of scoured bars, such that they are gradually lost. This project, by adding considerable volumes of coarse sediment and creating functional floodplains, in addition to continued gravel introduction upstream, will allow moderate depths of bed scour to occur on bars and reduce the risk of losing these bars.

5.2.5. Attribute 5: Balanced fine and coarse sediment supply, and routing of those sediments downstream.

A properly functioning river reach should transport sediment at approximately the same rate as that supplied from the upstream watershed. A balanced sediment budget also implies bedload transport continuity, meaning that most particles, over time, will be moved downstream through the reach during high flow events. “Sediment” can be broadly classified as coarse (gravels and cobbles) and fine (sands and silts). An adequate coarse sediment supply is critical for the river to create and adjust its channel dimensions, form bars, and transport sediment. Whiskeytown Dam, Saeltzer Dam, and instream gravel mining have significantly reduced coarse sediment supply in the project reach. Additionally, reduced flows from Whiskeytown Dam have allowed fine sediments delivered by the lower watershed to accumulate within the low-flow channel. The proposed project will fill pits that impede bedload routing, redefine a properly sized bankfull channel to improve bedload transport and routing, and recreate a functional floodplain that will encourage fine sediment deposition.

5.2.6. Attribute 6: A migrating or avulsing channel

Another important threshold that defines a “dynamic” stream channel is a migrating or avulsing channel. Dynamic alluvial channels episodically migrate through their floodplains between valley walls. Channel migration occurs at variable rates depending upon flow magnitude/duration, sediment supply, and influence of riparian vegetation. In large, relatively infrequent storm events (greater than 10-yr storm), the channel may avulse, completely changing its channel location. Channel migration creates and maintains channel and floodplain complexity by adjusting width and bank slope, by providing input of large woody debris from eroding banks, by creating new floodplain surfaces on the inside of meander bends, and by creating new seedbeds on these floodplains that encourage riparian vegetation colonization.

Because nearly all the Clear Creek floodway is under Federal or State ownership (with no structures in the floodway), Clear Creek is one of few regulated Central Valley rivers where channel migration can be encouraged. However, channel migration immediately after construction could potentially negate much of the riparian vegetation plantings. The channel rehabilitation project involves substantial earthmoving activity, which exposes the project to greater risk of adjustment in the first few years before vegetation growth provides some bank stability. There is a trade-off between using structural and/or bio-technical bank protection to provide some stability in the first few seasons, while allowing channel migration and avulsion in the future. In addition, there are several locations where channel change is not desirable in the first 5 years, because the channel could relocate into its previous location before the floodplain riparian forests become well established. These locations are typically where the design channel diverges greatly from the existing channel, and the risk of channel recapture is sufficient to warrant use of bio-technical bank protection. At most other locations, much smaller scale bio-technical bank protection is proposed, and many sites would only receive vegetation treatments. This will, over time and combined with episodic high flows, encourage channel migration.

Increasing the frequency and rate of channel migration in the future will be critical to discourage a new riparian berm forming at the project site. Unless flood flow releases from Whiskeytown Dam are improved, it is likely that a new riparian berm will become established within the design channel. Such a riparian berm typically prevents channel migration, except in larger events (greater than 10 to 20-yr magnitude floods), and would prevent many of these alluvial attributes to occur properly. This project encourages channel migration by rebuilding alluvial banks on the outside of meander bends and adding considerable volumes of coarse sediment into the channel, although a few sections of the design channel will have some bioengineering to reduce channel migration for the first few years.

5.2.7. Attribute 7: A functional floodplain

A functional floodplain is defined as a flat surface outside the bankfull channel that is frequently flooded, induces fine sediment deposition, and supports naturally regenerating riparian vegetation. Functional floodplains, typically inundated once annually on average, provide water storage during floods that attenuates flood peaks, and provides suitable locations for riparian vegetation establishment. A properly sized bankfull channel and floodplain provide sufficient channel confinement to maintain important geomorphic processes (bed mobility and sediment transport), yet allows floodplain overflow during larger flows. This process reduces the rate of increasing shear stress in the bankfull channel, provides floodplain scour and deposition to encourage riparian vegetation complexity, and encourages fine sediment deposition. Presently, there are very few functional floodplains in lower Clear Creek. Pre-Whiskeytown Dam floodplains are now either perched at a level which is only rarely inundated (functionally a terrace now), or have been excavated so that the surface is inundated for extended periods every year and does not provide the confinement necessary for coarse sediment transport.

A primary goal of this project is to re-create functional floodplains. This will be accomplished by raising (filling in pits) and/or lowering (cutting down pre-Whiskeytown Dam floodplains) existing surfaces to flood during discharges exceeding bankfull discharge (Figure 12). Newly constructed floodplains will not be flat and homogenous; complex floodplain micro-topography will be constructed to simulate high flow scour channels, and because these scour channels will be closer to the water table, natural riparian regeneration will be encouraged. These channels will be no more than 1-2 feet deep, and 30-70 feet wide. Grading in other floodplain areas will create a series of swales and low mounds, not hydraulically connected to overbank flows, although all these surfaces would be inundated in 3 to 5-yr events. Substrate variation, such as silts and fine sands, will be placed on floodplains to add complexity. Rapid vegetation growth will add roughness to floodplains, inducing fine sediment deposition during overbank flood events within a few years after construction.

5.2.8. Attribute 8: Self-sustaining, dynamic riparian vegetation.

Creating self-sustaining, dynamic riparian vegetation is directly linked to dynamic channel behavior and to functional floodplains. Historical aerial photographs of lower Clear Creek do not show large continuous riparian forests found in lower reaches of other Central Valley Rivers. Instead, due to the moderate gradient and channel avulsions, riparian vegetation occurred in a mosaic of strips and patches, usually associated with abandoned primary channels and high flow scour channels on floodplains. The process of channel migration, channel avulsion, and local removal of riparian vegetation during large floods created a diverse riparian vegetation, both in species and age class. Riparian vegetation also likely consisted of a diverse under and over-story species, and diverse structure, age, species, and composition provided maximum habitat value to birds and terrestrial species. A complex patch structure also increases the edge effect and increases biodiversity.

This project will address this attribute through a variety of methods: (1) preserving as much of the existing riparian vegetation as possible, (2) planting of a wide variety of species in a complex arrangement of vegetation series, which are based on those associations found in undisturbed riparian communities in a similar setting to Clear Creek, and (3) creating “seed beds” to encourage natural riparian regeneration. Saving existing vegetation stands within 2-3 feet of design topography will provide immediate channel stability in certain areas, and provide some greenery immediately after construction. Riparian planting will be extensive, occurring on most new surfaces, but as a patchwork that mimics riparian vegetation patterns in existing high flow scour channels. Seed beds will be sowed in constructed high flow scour channels, but will be dressed with deeper topsoil and not manually revegetated. These seed beds will be experiments to test whether natural riparian regeneration can assume a more substantial role in future revegetation efforts.

5.3. CLEAR CREEK REHABILITATION OBJECTIVES

Objectives of the Lower Clear Creek Floodway Rehabilitation Project are:

- Reverse channel degradation caused by historic aggregate extraction in the Mined Reach by reconstructing a properly sized bankfull channel and floodplain;
- Restore the ability of the channel to route coarse sediment downstream and deposit fine sediment on floodplain surfaces;
- Restore native riparian vegetation on floodplain and terrace surfaces by focusing on species that provide canopy structure and removing competing exotic species;
- Reduce salmonid stranding and mortality in floodplain extraction pits;
- Provide improved habitat conditions for native fish and wildlife species including priority salmonid species of central concern to CALFED, CVPIA, and AFRP programs;

These objectives will be met using the healthy river attributes as a guide. The following section provides a detailed discussion of the project design and the basis for evaluating the project.

6. CHANNEL DESIGN

There are three primary disciplines to integrate into an overall project design: channel morphology, riparian revegetation, and wetland design and revegetation. This section describes design concepts, processes, and results for channel morphology. Later sections discuss the design concepts, processes, and guidelines for riparian vegetation and off-channel wetland design.

6.1. CHANNEL DESIGN OVERVIEW

The goal of the channel and floodplain design for the Project Reach and the Reading Bar site is to restore a dynamic, properly sized alluvial channel morphology. More specifically, design objectives include:

- Re-establish an alternate bar morphology, with riffles, exposed bars, and deep pools.
- Channel will transport D_{84} particle size at flows slightly less than the anticipated future channel forming discharge (3,000 cfs), and coarse sediment can route through the reach.
- Floodplain will begin to inundate at flows slightly less than the anticipated future channel forming discharge (3,000 cfs), and fine sediments transported in suspension will deposit on floodplain surface.
- Channel can migrate across floodway during flows equal to or larger than the anticipated future channel forming discharge (3,000 cfs). Lateral channel movement is a desired outcome, not a failure.
- Raise bankfull channel at least three feet above clay hardpan to convert most of channelbed back to a gravel and cobble surface.
- Create floodplain micro-topography that simulates observed pre-dam high flow scour channels or abandoned primary channels. Revegetate many of these channels with native riparian vegetation, while leaving some unvegetated to experimentally evaluate whether natural riparian revegetation can occur (seed beds).
- Reduce the particle size in the design bankfull channel (Phase 3 and 4) by using borrow materials from the Former Shooting Gallery Site, of which 98% of the materials are finer than 6 inches.
- Evaluate whether we can cost-effectively screen out particles finer than ¼-inch to construct the design bankfull channel and create high quality aquatic habitat.

To achieve these channel design objectives, our pre-design development process required the following geomorphic evaluation:

1. Evaluate changes in the Project Reach due to gold mining, gravel mining, and flow and sediment regulation from upstream dams.
2. Evaluate historic and existing channel forming flow regime.

3. Evaluate contemporary sediment transport conditions.
4. Assume future bankfull discharge based on anticipated future hydrologic regime, and evaluate whether this discharge is sufficient to transport coarse sediment.
5. Measure local channel geometry in pseudo-reference reaches, evaluate regional channel geometry relationships from the literature, and evaluate whether the bankfull discharge in the design channel geometry is capable of transporting coarse sediment.
6. Identify clay hardpan location and depth in project site to identify constraints on channel alignment.

6.2. SUMMARY OF GEOMORPHIC AND HYDROLOGIC EVALUATION

Steps 1-7 are described in the following sub-sections for the Project Reach. These results will be applied to the Project Site channel design and the Reading Bar floodplain design.

6.2.1. Geomorphic Analysis

Many channel restoration projects have failed because designers have not considered the natural channel form of the channel. Practitioners often attempt to redesign a meandering channel morphology in settings where the natural trend for the stream is to be braided (e.g., “restoring” channels in alluvial fans). If a meandering channel is designed for a stream that has a natural tendency to be braided, the project will eventually fail as the stream evolves back into a braided system. Historical conditions suggest that the morphology of Clear Creek was in the transition between meandering and braided (Figure 9), which is supported by pre-Whiskeytown Dam aerial photos (Figures 5 and 6). Human manipulations to the flow and sediment regime through dams and land use practices will often shift this natural tendency in channel form and size. Whiskeytown Dam has reduced the bankfull discharge of Clear Creek, and Figure 9 predicts that this will move the Clear Creek channel morphology towards the meandering form.

Longitudinally, comparison of historical and recent profile surveys has shown that bed elevations in the project reach had been lowered by 3-7 feet or more as a result of instream gravel mining and reduced coarse sediment supply (Figure 4). The existing thalweg profile is typified as a step-pool profile, with clay hardpan horizons forming the steep steps, and long relatively flat run/pools between (Figure 13). Pit excavation and bar skimming, when followed by subsequent floods, caused rapid and extensive local channel down-cutting, which then caused head-cutting that migrated upstream. These processes continued until constrained by clay hardpan exposures, such that much of the present-day channelbed surface is exposed clay rather than alluvium. The proposed project will attempt to reverse this process by raising the bankfull channelbed surface above the clay hardpan with ¼-inch to 6-inch diameter gravel fill, and recreating floodplains by filling remaining instream pits and skimmed bars.

6.2.2. Hydrologic Analysis

The magnitude and frequency of channel-forming floods have been significantly reduced. Using the 1.5 and 2.0-year flood as representative descriptors of a channel-forming flood, pre-Whiskeytown Dam 1.5 to 2.0-year flood was 5,800 cfs and 7,500 cfs respectively, and the present-day 1.5 to 2.0-year flood is 2,260 cfs and 3,180 cfs respectively. The impact of both gravel mining and upstream flow and sediment regulation has virtually eliminated the ability of the 1.5 to 2.0-year flood to transport coarse sediment, let alone create and adjust channel dimensions. Additionally, a 2,260 to 3,180 cfs "channel forming" discharge does not transport coarse sediment at the downstream end of the Clear Creek canyon (as measured at the USGS gaging station near Igo), and only begins to mobilize a few D_{84} particles at an alternate bar sequence at Reading Bar.

Evaluating flood frequency of the 1-day and 3-day maximum daily average flows is another approach to consider for estimating channel-forming flow. The present-day 1.5 and 2.0 year flood for the 1-day maximum daily average flow is 930 cfs and 1,450 cfs, while the same flood indices for the 3-day maximum daily average flow is 650 cfs and 990 cfs. As with the instantaneous peak flood frequency indices, these flows are not large enough to do any significant geomorphic work, and are thus inadequate to maintain healthy channel morphology.

The draft channel designs assume a future design channel forming flood of 3,000 cfs; however, we are concerned that 3,000 cfs is insufficient to maintain the integrity of the rehabilitation project (i.e., prevent riparian encroachment) and satisfy important ecological goals (channel migration, bed mobility). The US Bureau of Reclamation is presently evaluating options for improving the magnitude of future channel forming flows, which will significantly improve project performance.

6.2.3. Sediment Transport

The design channel morphology should be able to adequately route coarse sediment supplied by upstream reaches, preferably avoiding significant (i.e., feet) aggradation or degradation of the channel. One of the difficulties of designing the Clear Creek channel to convey upstream coarse sediments is that the upstream supply is currently small due to Whiskeytown and Saeltzer dams, and that the supply will change once Saeltzer Dam is removed (estimated to occur in fall 2000). Saeltzer Dam most likely passes coarse sediment during higher flows (~10,000 cfs range), while Whiskeytown Dam does not allow any sediment to pass.

Future rates of coarse sediment supply are also expected to be small, based on coarse sediment transport samples collected in 1998 at the Igo gaging station (Figure 14). This site was chose to help evaluate "if Saeltzer Dam is removed, how much gravel is being supplied from the watershed downstream of Whiskeytown Dam, and is that volume sufficient to maintain alluvial storage in the project reach?" Samples were collected during flows of 2,600 cfs and 3,200 cfs, both of which were below a threshold of significant gravel movement, again indicating that larger channel forming flows are needed. Marginal tracer rock movement at a downstream alternate bar sequence corroborated this observation. Although transport of gravel at this site may be partly constrained by availability (supply-limited), so gravel transport would most likely increase if gravel were artificially introduced upstream. Small volumes of spawning gravel has been introduced immediately downstream of Saeltzer Dam to partially mitigate for the upstream dams, and to improve the quantity and quality of spawning habitat downstream. The primary channel design issue related to future sediment transport regimes is: a) when Saeltzer Dam is removed, how much, if any, of the sediment stored behind it be removed, and b) what rates of gravel augmentation will be needed to maintain alluvial storage in the project reach.

6.2.4. Bankfull Discharge

There are a variety of methods typically used to estimate bankfull discharge (assumed synonymous with channel-forming discharge) for a given river, including:

1. Assume bankfull discharge is approximated by the 1.5 to 2.0-year flood.
2. Estimate bankfull discharge by estimating the flow that begins to inundate a floodplain formed under the contemporary flow regime. On highly regulated rivers similar to Clear Creek, reduced peak flows impair or eliminate the ability to form a bankfull channel and floodplain. On Clear Creek, we have not seen classic floodplain indicators, just riparian sand berms along the channel margins that are typical of highly regulated rivers. Channel width at the top of riparian berms is 90 ft at the USGS gaging station near Igo (RM 10), 105 ft at the alternate bar downstream of Reading Bar (RM 7.7), and 130 ft at the Renshaw Riffle (RM 5.2), each of which is approximately 2,000 cfs to 3,000 cfs based on WY 1998 observations. The Renshaw Riffle is half the slope of the other sites; thus, the channel is appropriately 30 ft wider.
3. Estimate discharge by meander wavelength forming under the contemporary flow regime. A subtle alternate bar sequence immediately downstream of Reading Bar is the only location where a post-Whiskeytown Dam era meander has formed. The meander wavelength is 1,100 ft, and using Q_{bf}=0.00747$\lambda^{1.818}$ (Dury 1976), the predicted bankfull discharge for that meander wavelength is 2,500 cfs.
4. Estimate discharge from regional relationships of drainage area and channel dimensions. Dunne and Leopold (1978) relationship for SF area and Puget Sound area gives an equation of : $Q_{bkf} = 53D_A^{0.93}$ using a drainage area of 48.9 mi^2 below the dam which yields Q_{bkf} = 2,000 cfs. Adding 250 cfs for dam releases during the winter period results in a Q_{bkf} estimate of 2,250 cfs.
5. Estimate discharge that begins to mobilize the bed surface. Marked rocks at an alternate bar surface just began to mobilize in the center of the channel during a peak flow of 2,900 cfs (D_{84} = 130 mm versus a design D_{84} of 128 mm), while 3 miles upstream at the USGS gaging station, bedload sizes were all smaller than 32 mm during a peak flow of 3,200 cfs. We have recently added more bed mobility experiment sites to better understand bed mobility thresholds, but these sites will not provide any data until this coming high flow year (WY 2000).

The preliminary results of sediment sampling has led us to assume a design bankfull discharge for the project be a minimum of 3,000 cfs, and preferably higher. Flows of less than 3,000 cfs do not fully mobilize channelbed particles and are therefore incapable of performing the geomorphic functions necessary to rehabilitate the dynamic alluvial function of this reach. Channel geometry, planform geometry, and substrate size will be scaled to this discharge; however, the design bankfull discharge may need to be increased in the near future if it is insufficient to achieve geomorphic restoration objectives.

6.2.5. Meander geometry

Pre-dam meander wavelengths, based on 1952 air photos (Figures 5 and 6) and 1936 planform map (Figure 3), range between 1,200 ft and 2,300 ft, with a best value pre-dam prediction in the project reach of 1,600 ft. With the exception of one alternate bar sequence at the Reading Bar site, present-day meanders are merely remnants of pre-dam meanders, fossilized by riparian berms. This single alternate bar sequence formed because one bank was a talus slope of dredger tailings (no riparian berm could form), thus Clear Creek was provided a local source of coarse sediment to form alternate bars that we hypothesize are reasonably scaled to the post-dam flow regime. These incipient alternate bars have a meander wavelength of 1,050 ft. No other sites have been located that appear to provide dynamic alluvial features, unconstrained by vegetation encroachment or clay hardpan/valley wall confinement.

This field observation was compared to a number of regime equations published in the literature. We used three relationships to estimate meander wavelength. A bankfull discharge to meander wavelength relationship compiled by Dury (1976):

$$\lambda = 15.18 Q_{bf}^{0.55} \tag{1}$$

A bankfull width to meander wavelength relationship compiled by Leopold and Wolman (1957):

$$\lambda = 6.5 W_{bf}^{1.1} \tag{2}$$

A bankfull width to meander wavelength relationship compiled by Williams (1986):

$$\lambda = 7.5 W_{bf}^{1.12} \tag{3}$$

The bankfull discharge to meander wavelength relationship published by Dury (1976) contains considerable scatter, likely a result of combining streams with differing geologic controls (slope, valley confinement, particle size, etc). We used Equation 1 with the design bankfull discharge (3,000 cfs), and also tried another technique that may provide more site-specific applicability from this relationship. We first plotted the pre-dam estimated bankfull discharge (5,700) and pre-dam meander wavelength (1,600 ft), which plotted below Dury's regression line. We then "adjusted" the regression line by retaining the slope, but moving the line down so that it intersected the pre-dam values for Clear Creek. The resulting equation is:

$$\lambda = 13.75 Q_{bf}^{0.55} \tag{4}$$

Then, using the design bankfull discharge (3,000 cfs) in Equation 4, a meander wavelength is estimated from this locally adjusted meander wavelength relationship. Table 1 presents the results of these meander wavelength estimates. Based on results from Table 1, we are targeting design meander wavelengths at 1,200 ft. However, on-site constraints, including clay hardpan location, valley wall intrusions, and space within the floodway, prevents this wavelength applied to every meander. Furthermore, while a perfect 1,200 ft wavelength sinusoidal channel may be aesthetically pleasing from an airplane, it is rarely seen in nature. We use 1,200 ft as a target, but some wavelengths are longer and shorter, depending on local site conditions, radius of curvature, and clay hardpan location.

Method	Discharge (cfs)	Width (ft)	Predicted l (ft)
Reading Bar alternate bars	2,260 (post-dam 1.5 year flood)	105	1,100
Dury (Equation 1)	3,000	n/a	1,250
Dury (Equation 4)	3,000	n/a	1,120
Leopold and Wolman (Equation 2)	n/a	100	1,030
Williams (Equation 3)	n/a	100	1,300

Table 1. Summary of meander wavelength estimates

6.2.6. Preliminary Channel Geometry

Channel geometry was estimated iteratively as follows:

(1) Assuming a design maximum particle size of 6-inches, a D_{84} of 5 inches, and a high flow slope of 0.0023, apply bed mobility model to predict average depth needed to mobilize D_{84} particle size in a riffle.
(2) Setting that depth and slope constant, estimate Mannings roughness coefficient (0.028 for as-built conditions) for bankfull channel, and iteratively adjust channel width until bankfull discharge is conveyed by bankfull channel.
(3) Compare resultant width and depth with literature predictions and nearby reference reaches.

Bed mobility can be estimated for a simple channel geometry using Shields equation (Equation 5) if: 1) particle size, energy slope, water density, and sediment density is known, and 2) if dimensionless critical shear stress (τ^*_c) is estimated.

$$\text{Critical depth} = \frac{(\rho_s - \rho_w)(\tau_c^*)(D_{84})}{\rho_w (Slope)} \quad (5)$$

Dimensionless critical shear stress values can be predicted from models (e.g., Parker et al., 1982; Andrews, 1994), as well as by back-calculating from marked rock experiments. For D_{84} particle size, a critical shear stress value of 0.02 is reasonable based on our back-calculations on the Trinity River and predictions in Andrews (1994). Using this value and D_{84}=128 mm, Slope of 0.00232, and water (ρ_w) and sediment density (ρ_s) of 1,000 kg/m^3 and 2,650 kg/m^3, respectively, the predicted depth where the D_{84} is mobilized is 6.0 ft. Increasing the depth to 6.1 ft and increasing channel width to 100 ft results in the channel able to convey 3,000 cfs using a Manning's *n* of 0.028, and begins to spill onto the floodplain when Manning's *n* increases to 0.035. The results of steps 1 and 2 is shown on an idealized riffle cross section (Figure 15) with a maximum depth of 6.1 ft and average depth of 4.7 ft. Using San Francisco Bay regional drainage area-bankfull channel relationships (Dunne and Leopold, 1978) predict an average channel depth of 4.5 ft and channel width of 70 ft using an unregulated drainage area of 48.9 mi^2. Hydraulic geometry relationships presented in Dury (1976) predict average bankfull channel depth of at a 3,000 cfs bankfull discharge predict average channel depth of 7 ft and channel width of 110 ft (Dury, 1976).

Finally, field indicators of bankfull channel were poor at best. Channel width at the top of the riparian berms are 90 ft at the USGS gaging station near Igo (Figure 16, river mile 10), 105 ft at the alternate bar downstream of Reading Bar (Figure 17, river mile 7), and 130 ft at the Renshaw Riffle (Figure 18, river mile 5). Average channel depths are 4.8 ft, 5.6 ft, and 6.1 ft, respectively. Corresponding water surface slopes at flows near 3,000 cfs are 0.0033 at the USGS site, 0.00314 at the Reading Bar site, and 0.00061 at the Renshaw Riffle. The expected channel gradient at the Project site (0.0023) is slightly less than the USGS site and Reading Bar site, but much steeper than the Renshaw Riffle. Therefore, channel dimensions at the USGS site and Reading Bar site may be slightly smaller than that expected at the Project site, and dimensions at the Renshaw riffle would be larger than that expected at the Project site. The significantly lower slope at the Renshaw Riffle explains why the channel width and depth are larger than at the other sites. Based on these observations and estimates, we targeted a design bankfull discharge of 3,000 cfs, bankfull width of between 100-110 feet, a maximum bankfull depth of 6 feet, and a bankfull cross sectional area of 450-550 ft^2.

An idealized pool cross section template was also developed using existing pool/point bar morphology observed on-site (Figure 19). Bankfull channel width and average depth values are approximately the same as the riffle cross section templates, but maximum depth is significantly larger (10 ft). Additionally, point bar face slopes were set at 8:1 (horizontal:vertical) based on field observations.

The channel design was only evaluated for coarse sediment transport thresholds, not for its ability to route a presently unknown coarse sediment supply from the upper watershed. We are currently applying a modified version of Parker (1990) surface based coarse sediment transport model to evaluate a variety of coarse sediment supply rates to bracket Saeltzer Dam sediment removal options, as well as help develop gravel introduction rate recommendations to help maintain the restoration project. This effort will be completed in the fall of 2000.

6.2.7. Clay hardpan constraints

Reducing the amount of existing clay hardpan exposure within the bankfull channel is a priority rehabilitation objective. The clay hardpan surface undulates throughout the project reach, sometimes at a depth of 20 ft below the water table to being exposed on the banks. Therefore, the location and elevation of the clay hardpan surface is a significant constraint on the channel design. Presently, the clay hardpan provides most of the riffle control. With the exception of the upstream grade control, riffle control should be converted back to gravel and cobbles because the clay hardpan severely limits channel function and available habitat. Excavation of channel segments into clay hardpan would lock the channel into place, preclude the dynamic channel behavior we are targeting.

To evaluate the extent of clay hardpan constraints along potential channel alignments, we undertook an extensive test pit program. We mapped surface exposures of clay hardpan and excavated over 70 test pits at the Project site to define alluvial depths to clay hardpan (Figure 20). This investigation confirmed the extent of clay hardpan in certain key areas, which when combined with profile and fill volume considerations, led us to propose a new channel alignment that avoided the main clay hardpan locations. Clay hardpan location and elevation has become the critical factor in channel alignment because the general floodway surface has been lowered from instream mining. Therefore, the solution is twofold: raise the floodway surface above the clay hardpan by filling with gravel and cobbles from borrow sites, and re-aligning the channel to locations where the clay hardpan is at a lower elevation. Filling the floodway will also reduce the knickpoints shown on Figure 13, which reduces the risk of additional knickpoints developing and migrating upstream.

6.2.8. Borrow material constraints

Borrow materials are very different between Reading Bar and the Former Shooting Gallery borrow sites. Reading Bar was formed when sediment transported through the confined Clear Creek canyon deposited when the valley walls widened just beyond the present-day Clear Creek Bridge. Because this area is the first depositional area out of the canyon, much of the bar contains large cobbles and small boulders, in addition to gravel and sand. In contrast, the alluvial material to be borrowed from the Former Shooting Gallery appears to have come from the small gulch entering from the north (Figure 26), such that the particle size is much smaller (gravels and cobbles). Materials testing at the Former Shooting Gallery borrow site suggest that 98 percent of the material is finer than 6 inches and 84 percent finer than 3 inches. Therefore, for Phase 2, we recommend using the coarsest materials (boulders) at the Reading Bar site to fill the deep pits, and cap the pits (new floodplains) with gravels and cobbles from Reading Bar.

Because Phase 3 focuses on reconstructing the bankfull channel and near-channel floodplains, construction materials should be sized small enough to be frequently mobilized by the design bankfull discharge. In addition, these size classes should be within the range of particle sizes preferred by spawning salmon and steelhead. If the finer sediments less than 4 mm are removed (via screening) from the Former Shooting Gallery borrow materials, the D_{84} increases to 5.3 inches (135 mm) and the D_{50} increases to 1.6 inches (40 mm), which are within the range of preferred substrate sizes of chinook salmon (Kondolf and Wolman, 1993). Therefore, materials obtained from the Former Shooting Gallery should better satisfy particle size requirements than those obtained from coarser portions of the Reading Bar borrow site.

6.3. PHASE 2-4 CHANNEL DESIGN PARAMETERS

The preceding geomorphic evaluation resulted in the draft channel design parameters summarized in Table 2. We emphasize that these dimensions are targets, not absolutes; dimensions of most natural channels are extremely variable, and channel relationships found in the literature usually provide only the likely tendency of channel dimensions. Additionally, we expect these dimensions to naturally adjust as floods occur in the future.

Channel parameter	Dimension
Target channel morphology	**Meandering with scour channels**
Existing channel alignment gradient	**0.0032**
Design channel alignment gradient	**0.0023**
Increase in design channel length	**1,100 ft**
Target design meander wavelength	**1,100 ft**
Design bankfull discharge (channel forming flood)	**3,000 cfs**
Design maximum (D_{98}) particle size	**6 inches (152 mm)**
Design maximum (D_{84}) particle size	**5 inches (128 mm)**
Design bankfull channel width	**100 ft**
Design low flow (100 cfs) channel width	**50 ft**
Design bankfull channel average depth in riffles	**4.9 ft**
Design bankfull channel maximum depth in riffles	**6.1 ft**
Design low flow (100 cfs) channel depth in riffles	**1.5 ft**
Design low flow (100 cfs) channel depth in pools	**8 ft**

Table 2. Summary of proposed channel dimensions for Project Reach channel design.

As stated in previous sections, the existing 2.0-year flood (3,100 cfs) does not provide the channel forming function expected of it. Therefore, there is considerable risk that the infrequency of bedload transport and channel migration will allow riparian vegetation to re-fossilize the reconstructed channel. If this occurs, many of the important objectives of the project would not be realized. Additionally, there was considerable uncertainty as to when and if Saeltzer Dam would be removed, and the resulting change in coarse sediment transport into the project reach. It appears that Saeltzer Dam will be removed in fall 2000, with at least 50% of the sediment removed, although this estimate has not been finalized. Sediment Transport modeling is now underway that will provide some predictive capability to expected outcomes of Saeltzer Dam removal, and additional modeling is underway to refine Phase 3 and 4 channel morphology to accommodate the expected coarse sediment supply. No effective discharge analysis was performed at the project reach because the future sediment supply was dependent upon Saeltzer Dam removal; this analysis will provide useful design information once Saeltzer Dam removal is complete.

The phasing of the project was set up so that the channel reconstruction phases (Phase 3 and 4) would occur in year 2001 and 2002, allowing time for Reclamation to evaluate alternative ways to increase the magnitude of the channel forming flood, finalize Saeltzer Dam removal plans, and for the design team to collect additional geomorphic information to better document geomorphic response to flows exceeding 3,000 cfs. Therefore, the channel dimensions listed in Table 2 may be adjusted in the future if the anticipated channel-forming flood can be improved.

6.4. TOPOGRAPHIC DESIGN

The design parameters developed in Section 6.3 now need to be converted into a three-dimensional channel design. This is developed from the following two dimensional templates: cross sections showing typical riffle and pool geometry, planform alignment showing meander pattern and pool/riffle sequences, and vertical profile showing elevational control of the thalweg and floodplains.

6.4.1. Planform alignment

Using a target meander wavelength of 1,100 ft, a planform alignment was developed that avoided shallow clay hardpan exposures (Figure 20). The selected alignment abandons the existing channel at three locations: 1) upstream end of the project (proposed station 192+00 to 215+00) through the exposed gravel bar with deep alluvium, 2) middle of project (proposed station 155+00 to 181+00) to avoid the knickpoint shown in Figure 13, and 3) the downstream end of the project to abandon the chute and restore the historic channel location on the north side of the valley (proposed station 117+00 to 153+00). This proposed alignment increases channel length by 1,100 ft, and decrease channel gradient during bankfull discharge from 0.0030 to 0.0023. This alignment also reduces fill volume needed to construct floodplains in the vicinity of the knickpoint. Test pits indicate that depths to clay hardpan are a minimum of 5 feet along this alignment, providing a significant amount of alluvial cover.

While a primary objective of this project is a dynamic channel morphology, there are three locations where we would prefer that the realigned channel <u>not</u> recapture its old location for 3 to 5 years after construction:

- Proposed alignment station 214+00, the first diversion point at the upstream end of the project.
- Proposed alignment station 181+00, the diversion point to avoid the most pronounced clay hardpan knickpoint at the project.
- Proposed alignment station 153+00, the diversion point of the proposed channel into its historic northern location, avoiding the chute.

Bioengineering protection should be installed at the outside of the meander bends at these locations to reduce the risk of channel recapture. The bioengineering plan is described in Section 5.10.

6.4.2. Channel Profile at Project Reach

After selecting a channel alignment, we examined the profile throughout the project reach and for some distance upstream and downstream of the project area. We first identified upstream and downstream grade control, and determined the elevation of that control. We then drew a straight-line between these channel grade controls as an initial target for design riffle crests to intersect this line. Based on the alignment and specific sub-reach objectives, this linear profile was then adjusted as follows. Two short, relatively straight reaches that are lower gradient than the overall channel gradient were designed to be low gradient spawning riffles (similar to the Renshaw Riffle and the downstream end of the Chute channel in Phase 4). Decreasing the thalweg and floodplain slopes in these two reaches required the remaining reaches to become slightly steeper to maintain the overall design channel gradient. The design thalweg profile at this point was a series of straight lines that riffle crests were to intersect.

The next step was to superimpose a more detailed thalweg design profile onto the existing ground surface along the design channel alignment (Figure 21). The design channel alignment defined where pools and riffles were located: pools coincided with meander bends, and riffles connected pools as transverse bars. Where pools in the design alignment coincided with existing pools, the existing pool profile was retained. Pool depths ranged from 4 to 10 feet depending on the radius of curvature of the meander bend (smaller radius = greater flow convergence = deeper pool). Riffle and pool boundaries and elevations, identified on the design channel alignment, were transferred to the design thalweg profile.

After refinement of the profile, we determined floodplain elevations based on a uniform offset of 6.0 feet above the riffle crest elevations. These new floodplain elevations were then extended across the floodplain to an intersection with the valley edge or other higher ground feature (e.g., existing riparian stand, etc.). We then evaluated the difference between existing surface elevation and design floodplain elevation to determine which existing vegetation could be saved from disturbance.

Within the design channel we developed detailed pool geometry typically based on expected low-flow pool depths of 6-8 feet. These pool geometries reflect the characteristics of pools in less disturbed channels, including location of maximum pool depth relative to meander bend geometry, shape of the associated point bar, pool tail geometry and transition into riffle crest. While we are designing the channel with quantitative design criteria, our intent is for the constructed channel to self-adjust in the future. We cannot design and construct a perfect reflection of what would be created by natural processes in the future because the channel we are designing for has no set stable endpoint. It simply continues adjusting.

Refinement of the typical floodplain elevations was then made to this target channel morphology to add complexity to the constructed surface. A pattern of high flow overbank channels was delineated to mimic natural floodplain complexity and provide for a greater variety of geomorphic settings for riparian plantings.

The design channel was then subjected to hydraulic modeling using HEC-RAS to verify hydraulic performance, including channel and floodplain velocities and shear stress, overbank flow locations and quantities, and other hydraulic parameters.

The final step in the design process involved refinement of floodplain topography to daylight design topography to existing ground, in order to refine cut/fill areas, vegetation preservation areas, and clearly define the limits of the construction zone.

6.4.3. Slope

Existing bed elevations at the upstream end of the project reach are 468.0 feet at station 214+50. At this location, however, a clay ridge controls the entrance to the design channel. We propose excavating through the clay ridge approximately two feet to match the existing channel thalweg elevation, thus providing an initial thalweg elevation of 466.0 feet. The exit elevation at the downstream end of Phase 4 is 443.7 feet at station

118+00. Total drop, therefore, is 22.3 feet. Overall length of existing channel is 9,650 feet, for a design riffle crest slope of 0.0023 ft/ft.

Implementing Phase 3 and Phase 4 channel relocation and reconstruction will increase the total channel length in the project reach by 1,100 ft total. Assuming the beginning and end invert elevation would remain the same, channel slope through the reach would be reduced from 0.0030 ft/ft to 0.0023 ft/ft.

6.4.4. Floodplain Width and Elevation

Historical evidence suggests that most of the valley floor was readily accessed by flood flows, which is no longer true due to channel incision and gravel mining impacts. Surfaces that were clearly functional floodplains in 1952 are now terraces, most of which were not even accessed in the 1997 and 1998 high flows (13,000 cfs to 16,000 cfs, 10-20 year recurrence interval events). The current design will re-establish floodplains to the base of most valley walls, recreating valley-wide functional floodplains (Figure 24). Scour channels that drain back to the main channel have been designed 1 to 3 feet lower than the general floodplain elevation to provide topographic diversity on the floodplain, help reduce juvenile salmonid stranding, and provide natural riparian regeneration seedbeds. Piezometers have been installed at many locations at the project site and borrow sites to document seasonal variations in water table elevations, which have assisted greatly in designing scour channel elevations, estimating riparian cutting installation depths, and designing off-channel wetlands.

6.5. HYDRAULIC MODEL EVALUATION OF BANKFULL CHANNEL

After selection of a channel alignment, we developed a hydraulic model of the proposed channel to assess hydraulic variables and verify the design assumptions regarding slope, depths, velocities, and channel/floodplain conveyance. The modeling is based on the Corps of Engineers HEC-RAS Water Surface Profile Model. Boss RMS for AutoCAD software was used to define the geometric parameters of the hydraulic model for the proposed Project site design. We created 51 cross sections extending from proposed alignment station 118+00 to 218+00. Cross section data was generated from the proposed design channel topographic model (Figure 22). In general, the cross sections were spaced approximately 200 feet apart, with the only minor divergence from the design channel stationing to reflect anticipated channel flow paths.

Two runs were performed: estimating "as-built" conditions with main channel Manning's *n* values of 0.028, and one with future conditions (with additional vegetative and form roughness) using Manning's *n* values of 0.035. The as-built Manning's *n* value is based on recent back-calculations on a channel rehabilitation project on the lower Tuolumne River, which has slightly smaller particle size and half the slope as Clear Creek. Therefore, the 0.028 roughness value applied to Clear Creek may be slightly low. The purpose of the model is to evaluate whether the design bankfull channel is just overtopped by the assumed bankfull discharge (3,000 cfs). Results of the modeling suggest that the proposed bankfull discharge is approximately 0.5 ft below the design floodplain elevation under as-built conditions (n=0.028), but is slightly higher than the design floodplain elevation under future conditions (Table 3). Average channel velocities at bankfull discharge are on the upper end of the rule of thumb (4-6 ft/s).

At the Reading Bar borrow site, we were fortunate to be able to observe water surface elevations during a 2,900 cfs runoff event that occurred on February 7, 1999. This water surface elevation was surveyed from Clear Creek bridge downstream past the lowermost extent of the Reading Bar Borrow Site, and used to design the floodplain elevation rather than modeling water surfaces with a HEC-RAS model.

While some adjustments could be made to the channel design to inundate the floodplain under as-built conditions (i.e., lower the floodplain), we feel that the present design is adequate because channel roughness will increase soon and we wish to preserve the confinement to transport sediment through the reach.

6.6. DESIGN UNCERTAINTIES AND RISK

There are five significant uncertainties in the project design and performance that require discussion.

6.6.1. <u>Radius of curvature and meander wavelength at upstream end of project</u>

The fossilized pre-dam channel morphology upstream of the project site has a longer meander wavelength and larger radius of curvature than that of the post-dam dimensions used in this channel design. Because large floods still occur, there is some risk that the first meander wavelength should be elongated and radius of curvature increased to provide a better transition between the two morphologies. This should also reduce some of the risk associated with the design channel avulsing back into the existing channel on the first meander. If Phase 3 is funded, we will re-evaluate this important first meander bend geometry.

6.6.2. <u>Aggradation caused by channel slope breaks</u>

As the design channel transitions into the existing channel at the far upstream end of the project (Figure 24), the design channel cuts into a clay hardpan ridge to connect to the existing channel. The proposed channel thalweg at this cut is approximately one foot higher than the thalweg in the existing channel, resulting in a local decrease in slope at design channel entrance. This can cause local sediment deposition, creating a medial bar near the entrance, which can induce recapture into the existing channel or general channel instability at the very beginning of the project. We extended the thalweg profile 1,500 ft upstream of the project site to evaluate whether this potential local slope break was exacerbated by a larger change in slope (Figure 21). This section of channel was historically gravel mined (Figure 5), and is now predominately exposed clay hardpan. The slope of the clay hardpan is slightly steeper than the design reach, suggesting that deposition at the upstream end may indeed be a potential problem. A mitigating factor is the riparian berm along the existing channel, which partially offsets the impact of lower slope by focusing stream energy in the center of the channel and increasing sediment

transport capacity (McBain and Trush, 1997). Regardless, this transition is the most critical component of the project, and may require some maintenance (sediment removal) in the first few years after project completion.

Other significant breaks in slope in the project reach is at the upstream end of each of the spawning riffles (Figure 21), where the slope drops from 0.0023 to 0.0015 to create preferential depths and velocities for chinook salmon spawning. In both cases, existing riparian vegetation along the channel margins will be retained, which should assist in routing sediment through the reach and reduce bank erosion. If deposition occurs at the heads of these riffles, then we need to evaluate whether maintenance needs to occur; recall that a primary objective of the project is to be dynamic and self-adjust, and we need to divorce ourselves from maintenance at some point after the project is completed.

6.6.3. Future channel contact with clay hardpan

The proposed channel alignment attempts to avoid most of the exposed clay hardpan within the project reach, and in those areas where the channel crosses clay hardpan, the channel will be raised off the hardpan by filling with gravels and cobbles. Obviously, if the channel design performs properly, the channel will migrate into areas of exposed clay again. The channel remaining on the clay hardpan for long periods of time is generally undesirable; we anticipate that these clay contacts are transitory, and the channel will eventually migrate back across the channel through alluvium. The risk of channel capture by clay exposures by lateral migration is unknown. A potentially more likely scenario is channel downcutting to the clay hardpan by inadequate coarse sediment supply from upstream sources. Removal of Saeltzer Dam and continued input of coarse sediment will reduce this risk (another component of the geomorphic evaluation phase of this project will be to recommend coarse sediment management downstream of Saeltzer Dam).

6.6.4. Impact to reaches downstream of the project

A typical byproduct of constructing a channel restoration project is an immediate increase in sediment supply as unconsolidated gravels, cobbles, and sands are made available to transport during floods, particularly in the first few years after project completion. Typically, during the first few sediment transport events, sediment transport is high and deposition can occur both in the project reach and the reach downstream of the project. Sediment transport will eventually decrease as an armor layer develops on the bed surface and riparian vegetation begins to increase channel stability. Aggradation may occur at the downstream end of the project (Figure 21), but because the channel is on exposed bedrock there, aggradation will actually improve conditions downstream of the project. The extensive riparian encroachment downstream of the project will minimize risk of lateral migration or riparian vegetation loss.

6.6.5. Braided versus meandering planform

Historically, Clear Creek was on the transition between a meandering and braided channel morphology (Figures 5 and 6). The 0.0030 channel slope and the proposed 0.0023 slope plot along the transition between braided and meandering channel morphology (Figure 9). Streams that are braided or near this transition are often converted to meandering streams due to flow and sediment regulation upstream (Ligon et al., 1995 and others). The effect of Whiskeytown and Saeltzer dams lowering flow and sediment supply, combined with the rehabilitation project lowering the channel slope and increasing riparian vegetation should move the stream morphology towards a more meandering morphology than braided morphology.

6.7. LONG TERM EXPECTATIONS

Future project reviewers may be unsure or not understand the performance expectations of the project by the designers. We have stated numerous times in this document that one of the goals of the project is to allow the channel to be dynamic; we expect it to move. In fact, if the channel is not dynamic, then our objectives have not been met. Channel movement is perhaps the most commonly perceived source of restoration project failure, followed by coarse sediment aggradation or degradation; therefore, we discuss some our expected performance of the project upon which future evaluators can put actual channel response into perspective.

6.7.1. Channel migration

Our conceptual model of how Clear Creek used to move across its valley floor is one of gradual movement during moderate to high flow years, and wholesale channel avulsion during rare large flood events exceeding 10-year flood recurrence. The risk of rapid migration or avulsion during moderate floods decreases with time after construction and revegetation is completed as vegetation helps stabilize the channel and floodplains. Acknowledging this risk immediately after project completion, our desire for future channel movement is similar to our conceptual model of pre-dam conditions: small migration rates during moderate flow years, and avulsion during larger flood years (Figure 23).

6.7.2. Coarse sediment scour and deposition

While most channel restoration projects tend to fail due to sediment burial, we feel the greatest risk to failure is downcutting back down to bedrock, even after sediment routing is restored through the Saeltzer Dam reach. We expect and encourage the bed surface to move, coarse sediments to be transported, and local areas of aggradation and degradation. Local aggradation and/or degradation of up to two feet may be normal for this type of stream. Larger degrees of aggradation and/or degradation would be much less desirable.

6.7.3. Floodplain performance

Natural functioning channels tend to deposit a portion of their fine sediment load onto floodplains during overbank flow events. It is our desire to re-establish this process by recreating functional floodplains. However, this process requires frequent overbank flows large enough to suspend sediment grains up to 2 mm in diameter in order for those grains to access and deposit on floodplains. While these flows still periodically occur, the magnitude and frequency of them has been greatly reduced, such that fine sediment is usually transported as bedload in the low flow channel rather than in suspension out of the low flow channel to be deposited onto floodplains. Therefore, we do not expect large volumes of fine sediment to deposit on constructed floodplains by flows less than 6,000 cfs.

We have attempted to design the simulated high flow scour channels to intersect the shallow groundwater table during the springtime when native woody riparian vegetation is casting its seed. These moist areas on the floodplain should provide excellent seedbed locations, and should produce large amounts of natural riparian regeneration. If Saeltzer Dam is removed and Townsend Ditch is decommissioned, water availability to north bank floodplains may decrease slightly due to the loss of seepage from the ditch (which probably elevated shallow groundwater table when diversions were occurring).

7. RIPARIAN REVEGETATION

Riparian revegetation is as important to project success as proper geomorphic channel design. Riparian vegetation provides much of the terrestrial and aquatic habitat in healthy river ecosystems. Riparian vegetation also stabilizes the riverbanks, slows floodwaters, stores fine sediment and creates hydraulic complexity that causes topographic channel. As will be discussed in the next section, historic riparian vegetation was typically patchy, separated by extensive open gravel bars. Revegetation efforts will mimic this pattern, but because of the changes to Clear Creek hydrology and loss of riparian forests throughout the California, the revegetation plan should create more extensive riparian vegetation than historically occurred. The long-term goal of riparian revegetation is to restore the extent, morphology, and dynamics of riparian vegetation within the floodway that can be maintained by the future flow regime, and the short-term goal is to provide additional stability for the floodway rehabilitation project.

7.1. HISTORICAL EVOLUTION

Describing historical conditions as a means to develop desired future conditions (reference conditions) is a common restoration approach. However, the cumulative impacts of historic land use and current flow and sediment regulation often make historic site descriptions impossible. While we may not achieve these reference conditions soon, they can still be rehabilitation goals. Unfortunately, extensive disturbance to channel morphology and riparian vegetation began in 1848 with the discovery of gold at Reading Bar, too early for settlers to document conditions in Clear Creek before this disturbance. Therefore, we must rely on old aerial photographs, conditions on nearby surrogate streams, and descriptions provided by scientific literature to describe desired riparian conditions and processes. The following sections attempt to paint the historical evolution of lower Clear Creek riparian vegetation, including the present-day initial condition that rehabilitation activities will build upon.

7.1.1. Project site

We are unsure whether placer or dredger gold mining occurred within the floodway near the project site; no remnant tailings are found along the stream channel. However, extensive dredger tailings on adjacent terraces suggests that the channel suffered the same fate as the terraces. Later floods most likely converted the mining tailings back to gravel bars and floodplains. The most significant impact to the reach (which this project is addressing) was instream gravel mining, and to a lesser extent, flow and sediment regulation by Whiskeytown Dam. Therefore, much of the historical context will be between pre- and post-gravel mining.

Riparian vegetation patterns before the dam and gravel mining generally occurred as two patterns:
1) stringer patches within the bankfull channel that established in high flow scour channels and abandoned main channels,
2) larger patches on floodplains and low terraces (Figures 5 and 6).

Pre- mining channel morphology at the Project Reach and Reading Bar was near the transition between a meandering and braided stream (Figures 5 and 6). Distinct riparian plant species are associated with different geomorphic surfaces and hydrologic indices (i.e., flood frequency). For example, Fremont cottonwoods tended to grow in high flow scour channels that were lower to the groundwater table, had fine sediments deposited there during floods (providing seedbeds), and were periodically cleared of herbaceous vegetation, allowing seedlings to initiate and establish. Different riparian vegetation cover types, called plant series (Sawyer and Keeler-Wolf, 1995) within the Clear Creek corridor are summarized in Appendix B Table 1. Fundamental associations between dominant plant series and geomorphic surfaces are shown in Table 4.

Plant Series	Recurrence Interval range	Pre-dam flood magnitudes (cfs)	Geomorphic surface
Narrowleaf willow	Summer baseflow to 1.5 year flood	25 to 6,000	Within bankfull channel, in scour channels on floodplains
White alder	Summer baseflow to winter baseflow (those outside the bankfull channel are not dependent on streamflow)	100 to 500 (those within the bankfull channel)	Within bankfull channel on outsides of bends, base of valley walls near shallow groundwater
Fremont Cottonwood, Black willow	1.5 year to 20 year flood	6,000 to 20,000	On floodplains and along scour channels on floodplains
Valley Oak	> 10 year flood	>10,000	On upper floodplain surfaces, terraces, and hillsides

Table 4. Common plant series along Clear Creek, the associated range of discharges that the series falls within and the recurrence intervals of the discharges pre and post flow impairment.

This semi-natural riparian setting was first altered by reduced frequency, magnitude, and duration of high flows caused by Whiskeytown Dam. The natural regeneration process was for riparian plants that seed in the summer during low water to be highly successful at initiating, but less successful at establishing and maturing. The high flow regime was historically responsible for periodically scouring away most vegetation initiating along the low water surface, but the dam reduced high flows to the point where the plants were no longer scoured. As the plants matured, their roots immobilized the low flow channel to the point where only large floods >15,000 cfs could begin to remove them. This was evident soon after Whiskeytown Dam was completed (Pelzman, 1973). Narrowleaf willow (a summer seeder) and white alder are the dominant plant species growing along the low flow channel (Figure 10). Additionally, reducing the high flow regime negatively impacted Fremont cottonwood regeneration, they require disturbance to create favorable seeding conditions.

The more direct impact occurred in the 1970's and 1980's as instream gravel mining removed riparian vegetation when excavating bars and floodplains. Mining eliminated the natural geomorphic surfaces that riparian vegetation grew on, leaving a wide channel with numerous pits within the floodway. Various wetland and riparian plant species took advantage of the perennial and seasonal wetlands created by the off channel and in-channel gravel pits. Narrowleaf willow thickets and bands of white alder surround these wetlands.

7.1.2. Reading Bar and Former Shooting Gallery borrow sites

Both the Reading Bar and Former Shooting Gallery borrow sites were placer mined for gold in the 1850's, then later dredged. These actions "turned the ground over," removing all vegetation and leaving hummocks of dredger tailings. Small pockets of wetland vegetation surrounded by cottonwood stands remain between the dredger tailings and in lower areas mined for gravel. These borrow sites also contain numerous exotic plant species, particularly the aggressive tree of heaven (*Ailanthus altissma*), Himalaya blackberry (*Rubus discolor*) and star thistle (*Centaurea solstitialis*). Again, white alder and narrowleaf willow have encroached along the low flow channel at the Reading Bar site, immobilizing the channel.

7.2. REGULATORY AGENCY REVEGETATION GUIDELINES

The Design Team has contacted federal and state agencies (BLM, COE, USFWS, CDF&G) participating on the restoration team to obtain specific guidelines for riparian rehabilitation. Each agency has established wetland mitigation policies and personnel with vast experience in wetland rehabilitation projects however, specific restoration guidelines for species composition and planting designs were not available. The Design Team also contacted the Audubon Society and the Nature Conservancy and both of these two non-profit agencies had a considerable amount of revegetation information. COE has mitigation monitoring guidelines targeting compliance with Section 404 of the Clean Water Act. These guidelines do not identify specific restoration measures. Development of specific mitigation measures is the responsibility of the project proponent. The revegetation guidelines for this project were developed based on prior experience of the Design Team, discussions with resource agency experts and information provided in the literature.

7.3. GOALS AND OBJECTIVES

Recalling that the overall goal of the project is to rehabilitate the natural form and function of the channel and floodplain, the first step is to recreate the physical form of the channel and floodplain. This is described in Section 5. Revegetation objectives to achieve the project goal include:

1) Site planting --Revegetate reconstructed floodplains by planting patches of native riparian hardwoods at inundation frequencies appropriate for each species life history requirements.

Constructed floodplains and wetlands will be revegetated in a way that reflects natural interactions between vegetation, hydrology, and channel morphology (planting species in their hydrologic niches). Riparian plant recruitment is episodic and patchy. Certain geomorphic surfaces are successfully colonized in some years, then as vegetation matures, high flows scour away patches of riparian vegetation. Integrating the establishing patches with scoured patches results in a historically diverse vegetation pattern along Clear Creek (Figure 5 and 6). To recreate this diversity, floodplains will be revegetated in a mosaic of patches. Planting patches will replace riparian vegetation on some surfaces, while leaving others exposed for natural plant recruitment (see next objective).

2) Promote natural regeneration/recruitment by spreading topsoil over some areas of reconstructed floodplains, creating favorable physical conditions for natural riparian hardwood regeneration.

Replanting will speed riparian dependent wildlife habitat recovery at wetlands and floodplains; however, this only creates even age patches of riparian vegetation, which is not representative of regionally undisturbed systems. Natural recruitment of most riparian species requires proper soil conditions (exposed fine sediments), correct timing of seed dispersal to coincide with wet soil conditions, and sufficiently wet soil for the plant to survive as a seedling. Constructing areas that provide favorable seed germination conditions when herbaceous and hardwood species are dispersing seeds will encourage natural recruitment. These areas will not be manually planted. If this approach appears successful, this type of natural revegetation effort should be contemplated in other areas to encourage multiage riparian stands and long-term habitat rehabilitation.

3) Minimize disturbance of existing riparian vegetation

Rehabilitation activities will not disturb any valley oaks in the reach; however, other upland associated species of oak may be removed, including Mexican Elderberry (*Sambucus mexicana*). Existing valley oaks will provide acorns for the revegetation effort, as well as contributing to future oak recruitment. Fremont cottonwoods will be preserved wherever possible because they are in low numbers along the creek. Cottonwoods that do need to be removed during construction will be cut up and used for cuttings. In some cases we will prune older trees a year prior to replanting so that these trees can supply one-year-old branches for planting.

4) Remove invasive exotic plant species and discourage future re-establishment.

Many exotic plant species within project and borrow sites will be removed during material excavation and floodplain regrading. Two hardwood species will be specifically targeted because of their aggressive colonization: tree of heaven (*Ailanthus altissma*) and black locust (*Robinia pseudoacacia*). Two herbaceous species will be targeted for removal: star thistle (*Centaurea solstitialis*) and Himalaya berry (*Rubus discolor*). The above ground portion and the stump/root wads of exotic plants will be removed. After initial removal, a maintenance program may be needed to discourage exotic species from displacing native riparian species established by this project.

7.4. FLOODPLAIN REVEGETATION DESIGN

Based on the objectives listed above, a riparian planting scheme was developed for restored geomorphic surfaces at the Project reach (Figure 24) and Reading Bar borrow site (Figure 25). The design mimics vegetation patterns found on the different geomorphic surfaces of less disturbed regional streams, and targets the following revegetation strategies for each geomorphic surface:

Point bars- Pre-dam point bars were exposed gravel and cobbles, with sporadic patches of narrow leaf willows. Where point bars still remain, flow regulation allowed them to be colonized by white alder and narrow leaf willows. Reconstructed point bars will not be revegetated, and riparian berms on un-mined point bars will be removed. Natural revegetation will occur on point bar surfaces.

High flow scour channels- High flow scour channels will be constructed to simulate those observed in pre-dam aerial photographs. These channels are closer to the groundwater table than the floodplains, are moist during spring seed dispersal due to positive groundwater gradient from the adjacent hillsides, and tend to trap fine sediment during high flows. When combined with coinciding hydrology and riparian seed dispersal, these areas encourage patches of riparian hardwood seeds to germinate. Some of these constructed high flow scour channels will be revegetated; others will remain unplanted to become potential seedbeds for future natural riparian regeneration. In the future, natural riparian regeneration of these surfaces should increase both structural and age class diversity of riparian vegetation within lower Clear Creek.

Floodplains- Floodplains will be constructed at an elevation where they are frequently inundated by anticipated future high flows (>3,000 cfs). Much of the revegetation will occur on these surfaces. Target species include Fremont cottonwood, black willow, mixed willow, arroyo willow, white alder, mulefat, and Mexican elderberry. Patch type series planting will also be implemented on floodplain surfaces.

Terraces- Terraces will not be constructed because they require larger volumes of fill to construct, and do not provide as much riparian habitat potential as floodplain surfaces. Existing terraces (many of them pre-dam floodplains) will not be revegetated, with existing senescent riparian or upland vegetation retained as seed sources.

7.4.1. Plant palette and revegetation strategy

There are two approaches to riparian revegetation. The first includes planting a full complement of plant species, canopy, mid-story, and under-story plants. While this is a more complete planting scheme, it is often cost prohibitive because the understory components. Furthermore, if the understory species are planted before a canopy has developed, the sun intolerant understory plants will have low survival. The second approach is focuses on planting the dominant tree and shrub species to provide cover and shade, which will eventually create the micro climatic conditions favorable for natural mid-story and under-story plant recruitment. We recommend the latter approach for revegetating lower Clear Creek.

Final riparian vegetation coverage combines revegetation on constructed surfaces and vegetation retained during project construction. Currently 20 plant series (or cover types) are found within the Clear Creek corridor, although not all are riparian or native to Clear Creek. Proposed revegetation will focus on 10 plant series (Appendix B, Table 2). Many of these plant series have identical species, but the composition varies by plant dominance (e.g., a Fremont cottonwood series has black willow, arroyo willow, and others, but the dominant species is Fremont cottonwood). This strategy limits the number of individual riparian plant species included to 12, and wetland emergent species to 4.

Construction activities will require some Mexican elderberry plants to be removed. Mexican elderberry is the host for the endangered Valley Elderberry Longhorn Beetle, and removal of elderberry plants will require consultation with USFWS under the federal Endangered Species Act (ESA) Typical mitigation for elderberry disturbance ranges from 3:1 to 5:1 for stems 1 inch in diameter or greater. Mexican elderberry is a component of many of the proposed planting series, and will planted along with other species (Figure 24). Consultation with the USFWS will ultimately determine specific mitigation requirements for impacts to elderberry that will occur during project implementation.

7.4.2. Patch planting

Figures 24, 25, and 26 show patches of riparian vegetation series to be planted (each patch is based on a unique plant series). Planting procedure, density, species within a patch, and planting arrangement need description for a contractor to be able to implement the riparian design. Each proposed patch shown in Figures 24, 25 and 26 could be planted by digging trenches perpendicular to stream flow for efficient implementation. Each patch would be planted with a unique assemblage of woody plant species, dominated by a certain species (Figure 27). Ideally, only 50% of the overall constructed floodplain area would be planted, with the remaining floodplain area unplanted to allow planted riparian canopies to grow and develop, to allow natural regeneration to occur, and to provide patchiness by leaving open areas.

The number of plants in a patch is based on the growth habits of a specific plant species. For example, mixed willow patches have a higher stem density than Fremont cottonwood patches. Planting densities in each patch are high for several reasons. The ideal outcome of revegetation is a patchy mosaic of Fremont cottonwood forests and shrubby willow thickets; mortality in planted patches is an ideal way to achieve this patchiness. The revegetation design relies on cuttings being planted into a shallow ground water table, The first year planting should have higher plant density to ensure revegetation success; if plant survival is too high to achieve a patchy morphology, subsequent revegetation efforts should increase the unplanted area and reduce planting density to create a desired vegetation patchiness.

Implementation of the revegetation effort should be done in a way to achieve the desired results (diversity of series, diversity of species, patchiness, open areas) in the most economical means possible. This can be accomplished by digging trenches perpendicular to streamflow to the winter groundwater table, and installing hardwood cuttings at the spacing indicated by the patch type (Table 5). Two cuttings could be planted at each planting location along the trench to increase plant survival. For example, in Fremont cottonwood patches, two cuttings are placed every 10 feet in the trench, contrasted to mixed willow patches where 2 cuttings are placed every 3 feet. Planting locations along trenches are randomized based on the starting location of the trench so that the revegetation does not appear as a row crop (cutting mortality within trenches will also help to alleviate the row crop appearance).

Patch/Series Type	Stand Growth Habits	Spacing
Fremont cottonwood	Forest	10 ft on center between trenches and 10 ft on center between plants, 2 cuttings per planting
Black willow	Forest	10 ft on center between trenches and 10 ft on center between plants, 2 cuttings per planting
White Alder	Forest	10 ft on center between trenches and 10 ft on center between plants, 2 cuttings or 1 container plant per planting
Mixed willow	Thicket	10 ft on center between trenches and 3 ft on center between plants, 2 cuttings per planting
Arroyo willow	Thicket	10 ft on center between trenches and 3 ft on center between plants, 2 cuttings per planting
Buttonbush	Shrub	5 ft on center between trenches and 5 ft on center between plants, 2 cuttings per planting
Mexican Elderberry	Shrub	5 ft on center between trenches and 5 ft on center between plants, 2 cuttings per planting
Mulefat	Shrub	5 ft on center between trenches and 5 ft on center between plants, 2 cuttings per planting
Bulrush	Rhizomatous	Wet planted, 2 ft on center between plants
Sedge	Rhizomatous	Rolled mats

Table 5. Proposed planting spacing for selected patch types based on different stand growth habits.

Within each series, the species composition is installed in the trench in the proportion of that series. For example, for the mulefat series, 80% should be mulefat, 10% should be red willow, and 10% should be arroyo willow (Appendix B, Table 2). These species would then be planted in the trench 5 ft apart in the following sequence:

MF – MF – MF – MF – RW - MF – MF – MF - MF – AW

Where MF= mulefat, RW=red willow, and AW=arroyo willow.

7.4.3. Exotic species control and weeding

Many exotic plant species within project and borrow sites should be removed during floodplain regrading, material excavation and wetland construction. Two hardwood species should be targeted for removal; tree of heaven (*Ailanthus altissma*) and black locust (*Robinia pseudoacacia*). Three herbaceous species should be targeted for removal where physically and economically possible, star thistle (*Centaurea solstitialis*), Johnson grass (*Sorghum halepense*), and Himalaya berry (*Rubus discolor*). The above-ground portion and the stump/root wads of exotic plants should be removed to discourage subsequent regeneration. However, a seed bank may still be present after construction, so an exotic plant removal program may be needed.

Clear Creek flows through an arid region of California, where plant establishment is often a function of not only seed availability, but also water. Revegetation projects that supply water in excess of that available through local precipitation (either through flood, sprinkler, or drip irrigation) often have problems with exotic weeds out-competing plantings that are irrigated. There may be a substantial exotic seed bank both in the soils that will be replanted, as well as those being imported. While there may not be a cost effective way to prevent annual herbaceous exotic plants from growing, exotic woody exotic plants should be removed annually. For a period of five years, the revegetated project including the borrow sites should be cleared of all sprouting exotic hardwoods. After five years, planted riparian vegetation should provide enough canopy cover to discourage the regeneration of exotic hardwoods.

7.4.4. Irrigation

Hardwood cuttings should not require irrigation because they will be planted to the depth of the winter groundwater table on floodplains, and we anticipate that the decline of this winter groundwater table should be at a rate less than the root growth rate of the cuttings (i.e., the roots can follow the declining groundwater table through the spring and summer). Soil moisture and groundwater will be the only water available to the hardwood cuttings; therefore it is imperative that cuttings be planted at the specified depths (Figure 27).

While we recommend that revegetation emphasize cuttings and natural regeneration, some plant series will require container and bareroot stock (e.g., white alder). Container and bareroot plant stock will require irrigation for the first three years to allow roots to grow down to the water table. A drip irrigation system should be installed to the plant series with container stock. Each plant should have two emitters, emitting a half-gallon of water an hour. Once installed, container stock should be watered for an entire day once every other week from June to October. Irrigation times will gradually be decreased over the three-year period to wean plants from irrigation. If needed, drip irrigation systems will be installed at both the project and borrow sites.

7.4.5. Plant protection

Newly planted riparian vegetation provides a succulent food source for many herbivores so revegetated areas may have to be protected, primarily from deer and beaver browsing. Other small mammals and insects may browse some plants, but the habitats that are being rehabilitated will eventually attract their predators. Our primary concern is beaver browsing. Beavers are known for their voracious appetite and their preference for willows and cottonwoods. Research has shown that “beavers appear to be restricted in the distance they can safely range away from open water – about 200 feet” (Nature Conservancy, 1998). The project will be reducing beaver habitat along the river by filling in mining pits, but wetland areas on terraces will remain, so beaver habitat will be reduced but not eliminated. Therefore, protection may require temporary depredation permits from CDFG, installing protective “cages” around individual plants, fencing off an entire revegetated area, installing plant quantities in excess of the numbers that we expect to ultimately survive, or treating a percentage of plantings with a mammal repellent (e.g., ROPEL). The decision on which protective measure to use will be based on cost, chance for success, ease of implementation and maintenance.

7.4.6. Long-term expectations

If 100 percent of planted riparian vegetation survives, nearly complete canopy coverage of the floodway will occur. Obviously, we do not expect 100 percent survival, so natural die-off of a portion of revegetated floodplains is expected. We also expect that future floods will cause channel migration and floodplain scour, destroying planted riparian vegetation in some areas, but also creating new seedbeds for natural riparian regeneration in the future. Planting will provide initial species variation, but only time, floods, and droughts will provide age class and structural diversity that is desired (Figure 23).

7.5. BIOTECHNICAL BANK REINFORCEMENT

As mentioned in Section 5, there are three meander bends within the project reach where channel migration into its old channel is undesirable for the first five years or so. Therefore, biotechnical bank reinforcement should be considered for these locations (Figure 24). Biotechinical bank reinforcement is a complement of more traditional bank protection (rock), and, softer biotechnical engineering (vegetation). Small boulders placed along the toe of the low water channel are combined with sod mats and brush mattresses to providing immediate structural reinforcement and longer-term vegetation benefits.

The outside bank of channel bends where biotechnical bank reinforcement will be constructed should have at least 3:1 slopes (H:V), with rock placed at the slope's toe. Slopes need to be shallower than 1:1 to facilitate sod mat and brush mattress placement. Two feet diameter (or smaller) boulders should be placed along the bank toe from the thalweg to the height of average summer low water (Figure 28). Boulder placement should start 100 feet upstream from the beginning of the corner and end 100 feet downstream. Boulder could be obtained from the north end of the Reading Bar borrow site.

Sedges (*Carex aquatilis*) provide substantial cohesive strength to substrates, making them ideal for bioengineering applications. Two approaches to sedge application are being considered, both require that the edges of the treated area be trenched and keyed into the bank to prevent it from being flanked and removed during floods. The first approach consists of placing living sedge sod along the average summer low water up the bank two feet (Figure 28). Sedge mats will need to be grown for one to two years in natural fiber netting (coir, jute, bog mat, or other comparable product). If possible, Clear Creek seed stock should be used for growing sedge mats, and mats should be installed using conventional sod installation techniques. After the sedge sod is installed a wider mesh coir fabric will be placed over the sod mats, "tying" them to the bank. The coir mesh fabric placed over the sod mats provides extra assurance that the sod mats will be able to withstand water velocities up 15 feet per second immediately after construction.

The second method being considered installs jute/coir mesh on the bank starting at the summer low water surface going up the bank three feet, and planting individual sedge "plugs" through the mesh. The advantage of the first method is that the structural integrity of a sedge mat is higher, potentially being able to withstand velocities greater than 15 feet per second, however the cost and pre-project preparation is higher. The second method is attractive because of lower costs; however, the immediate bank strength after construction is much lower and it will take two years (probably more) to achieve the same root strength as the sod mats.

Willows grow higher on the bank than sedges, are structurally strong, and can significantly reduce local water velocities along the bank as they mature. Willow brush mattressing will be installed from where sedges end to the break in slope where floodplain begins (Figure 28). While brush mattressing is material and labor intensive, it provides considerable strength immediately after installation. Brush mattressing consists of weaving live willow branches together to form a tight interlocking mattress. The mattress is attached to the bank using live willow stakes, and then cable (or jute string) is used to tie the mattress structure down. Because the primary structure is composed of living material, once the willows have rooted, the structure continues to grow stronger with time. As a dense willow thicket develops, water velocities will slow, inducing fine sediment deposition making these corners less prone to channel migration and channel recapture in these three critical meander bends.

8. OFF-CHANNEL WETLAND DESIGN

A small portion of the Reading Bar and approximately one-half of the Former Shooting Gallery borrow sites will be reclaimed as off-channel wetlands. Reclamation will include site grading and soil preparation to create favorable hydrology and soil conditions to achieve desired wetland function objectives. The borrow sites currently have small wetlands on-site; material excavation will enlarge and improve these wetlands. Vegetation within these existing wetlands is a complex of seasonal emergent herbaceous and woody riparian vegetation. Existing wetland plant species recolonized these sites following disturbances from historical gold and gravel mining activities and have low to moderate wildlife value. Currently wetland vegetation at these sites varies from sparsely vegetated to dense thickets, much more variable than the wetlands occurring within the project area.

8.1. OBJECTIVES

After borrow material is removed, the primary goal of creating off-channel wetlands is to create higher quality wetland habitats than those currently existing on-site and throughout the lower Clear Creek corridor.

Constructed wetlands at the Reading Bar and Former Shooting Gallery sites will target wetland dependent wildlife including aquatic amphibians (aquatic garter snake, western toad), waterfowl (mallard, wood duck), wading birds (great blue heron, great egret), and shorebirds (killdeer, spotted sandpiper). These habitats will also attract species that use wetlands for portions of their life history requirements such as riparian and upland birds (Black-headed grosbeak, Spotted towhee), upland reptiles and amphibians (western fence lizard, gopher snake), and various mammals (raccoons, deer).

General wetland objectives are:

- Design wetland areas that are seasonal and perennial. The lowest surfaces in the perennial wetland must be below the minimum groundwater table elevation to remain wet year-round.

- Create variable planform morphology to maximize edge effect, water depths and habitat diversity. The design will incorporate variable shapes, islands, peninsulas, and other topographic features to provide a physically diverse wetland.

- Design variable bench elevations to provide diverse microhabitats for emergent wetland and riparian vegetation. Benches will be constructed to provide variable water depths, leaving different “zones” for plant species colonization.

- Revegetate seasonal and perennial wetland habitats by planting native herbaceous and hardwood species within sites appropriate for each species life history requirements. Existing wetland habitats within the lower Clear Creek corridor are dominated by exotic and/or weedy hydrophytic vegetation resulting from random plant colonization following gravel-mining activities. Planting native wetland plants will create habitats with greater wildlife value and structural diversity than those currently occupying wetlands left from gravel and gold mining.

- Promote natural regeneration/recruitment of hydrophytic vegetation in constructed wetland areas by providing topographic contours and other suitable microsites with variable inundation regimes, creating favorable conditions for plant regeneration.

- Remove invasive exotic plant species and discourage future re-establishment

8.2. WETLAND TOPOGRAPHIC DESIGN

8.2.1. Reading Bar site

The Reading Bar site will consist of a 0.6-acre emergent wetland roughly circular in shape (Figure 25). The water table at this location is connected to Clear Creek, therefore, water elevations are expected to vary with flow, and the minimum expected water surface elevation will be at the summer low flow elevation (585 ft). Obligate wetland plant species are controlled and/or limited by the hydrologic regime in which they live. The species of plant that will survive in a given location depends on soil conditions, inundation period(s), and depth of inundation. Therefore, the constructed wetlands will incorporate various design depths to create different elevation zones, providing a variety of inundation regimes.

The off-channel wetland at the Reading Bar site will be isolated from Clear Creek by an earthen dike for flood flows up to 15,000 cfs. The "deep water" that isolates the island is designed to be 2 ft deep during summer low flow and up to 7 ft during a design bankfull discharge on Clear Creek. Benches will also be constructed to provide riparian vegetation surfaces on the perimeter of the wetland (Figure 25). Wetland side-slopes will be a minimum 3:1 to allow riparian vegetation to establish.

8.2.2. Former Shooting Gallery

Unlike the Reading Bar wetland, the water table at the Former Shooting Gallery site is not connected to Clear Creek; water levels will vary with groundwater elevation rather than streamflow. The maximum expected water surface elevation is 575 feet, as defined by the lowermost culvert outlet draining the site under Clear Creek Road. The minimum expected water surface elevation is currently unknown (although we do have piezometers installed to monitor water levels this summer). Until additional summer water table elevations are measured, we will assume a minimum water surface elevation of 571 feet. Islands within the wetland site are designed to be 9 ft above summer minimum water elevation and 5 ft above maximum water levels (Figure 26). Deep-water habitat is designed to be 4 feet deep during summer low water levels and 8 feet deep during maximum water levels. Wetland slopes should be at least minimum 3:1 to allow vegetation to establish. If practicable, fine materials will be placed over the wetland site to provide substrate suitable for emergent wetland plant growth.

Benches will be planted with wetland emergent vegetation, while islands, peninsulas, and higher benches planted with woody riparian vegetation (Figure 26). For example, at the former shooting gallery the bench located on the north side of the wetland will be revegetated as a Fremont cottonwood series, eventually providing additional wildlife habitats. The bench on the south side of the same wetland adjacent to Clear Creek Road also will be revegetated to provide visual and noise buffers. On the eastern edge of the wetland, a low patch of cottonwoods will be retained, with two peninsulas designed to radiate from it. Another peninsula is designed to radiate from the existing riparian bench on the southern side of the wetland. The peninsulas will be designed to be zero to four feet above the water surface (depending on time of year). A small creek draining into the wetland site from the northwest will provide flow and fine sediment to help maintain the wetland and improve function.

8.3. WETLAND REVEGETATION DESIGN

The topography, hydrology, and soils will be provided as part of the topographic design described above. There are two competing hypotheses on how these off-channel wetlands should be revegetated. The design team hypothesizes that strategic but limited planting of target native emergent wetland vegetation will give those preferred species a jump-start to invasive exotic species. We want to prevent the sites from being overrun with aggressive species that exclude other, wetland plant species; such as cattail marshes, which are typical of the lower Clear Creek corridor. Others hypothesize that natural recolonization will achieve the same revegetation goals in a less costly manner. Therefore, we recommend a combination of natural colonization and artificial planting of native wetland vegetation to provide the vegetative component of the wetland design. This will allow us to evaluate which method provides superior results.

The emergent portion of constructed off-channel wetlands will provide water depths up to approximately eight feet during the wet portion of the year, and as low as two feet during the summer. Emergent vegetation that provides high-value habitat, such as bulrush (*Scirpus* sp.), will be planted on shallower inundated benches and is uncommon locally. The constructed wetland habitats will also include islands and peninsulas for nesting, loafing, and other wildlife use. Slopes in the constructed wetlands will range from 3:1 in steep areas to between 8:1 and 10:1 in emergent bench areas. As previously discussed, existing vegetation will be incorporated into these areas to provide cover, habitat continuity, and additional vegetative structure.

Currently, borrow sites have hydrologic conditions suitable for wetland construction (as evident by the existing wetlands). Wetland construction will use existing surface and subsurface hydrology to create higher quality wetland habitats. We have installed piezometers at the Former Shooting Gallery borrow site, monitored groundwater table elevations through 2000, and used results to design the wetland depth (Figure 26). The created wetland habitats are characterized as seasonal emergent wetlands (perennial in wet years) much like the existing wetland features. However, the created wetlands will include additional microsites for natural plant colonization, maintain a longer inundation period, and through planting efforts, include plant species that are high quality to wildlife.

Designed wetland topography will create a variety of surfaces at different elevations, encouraging greater plant species diversity than current conditions (Table 6).

Surface	Hydrology	Target habitat	Vegetation series
Deep water	Perennial, 2-8 ft deep	Deep water, emergent	pondweed (floating and submerged) water lily
Emergent, emergent bench	Mostly perennial, some seasonal	Emergent	Bulrush, buttonbush
Riparian bench, peninsula	Infrequently inundated, 0 to 4 ft above water surface	Riparian emergent, riparian	Cottonwood, Arroyo willow, black willow, buttonbush
Island	Infrequently inundated, 0 to 9 ft above water surface	Riparian emergent, riparian, mesic at Former Shooting Gallery	Cottonwood, Arroyo willow, black willow, buttonbush, sedge

Table 6. Relationship of proposed emergent and riparian vegetation planting to constructed surfaces and expected hydrology.

9. REFERENCES

Andrews, E. D., 1994. Marginal bedload transport in a gravel stream, Sagehen Creek, California, *Water Resources Research*, Vol. 30, No. 7, pp. 2241-2250.

Binder, W., P. Jurging, and J. Karl, 1983. *Natural river engineering: characteristics and limitations*. Garten + Landschaft. 93:91-94.

Brookes, A., 1987. Restoring the sinuosity of artificially straightened stream channels, *Environmental Geology and Water Science*, 10:33-41.

Brookes, A. and F.D. Shields, Jr., 1996. River Channel Restoration, Guiding Principles for Sustainable Projects. John Wiley & Sons, Chichester, United Kingdom.

California Partners in Flight and Riparian Habitat Joint Venture, 1998. *The draft riparian bird conservation plan: a strategy for reversing the decline of birds and associated riparian species in California*. Sacramento, California.

Dunne, T. and L. B. Leopold, 1978. *Water in Environmental Planning*. W.H. Freeman and Company, New York.

Dury, G.H., 1976. Discharge prediction, present and former, from channel dimensions, *Journal of Hydrology*, Vol. 30, pp. 219-245.

Jungwirth, M., S. Muhar, and S. Schmutz, 1995. The effects of recreated instream and ecotone structures on the fish fauna of an epipotamal river. *Hydrobiologia*. 303:195-206.

Kondolf, G. M. and W. V. G. Matthews, 1993. *Management of coarse sediment on regulated rivers*, University of California: Water Resources Center.

Kondolf, G. M. and M. G. Wolman, 1993. The sizes of salmonid spawning gravels, Water Resources Bulletin, Vol. 29, No.7, pp. 2275-2285.

Leopold, L.B. and M.G. Wolman, 1957. River Channel Patterns: Braided, Meandering, and Straight, *USGS Professional Paper 282-B*, pp. 39-85.

Ligon, F.K., W.E. Dietrich, and W.J. Trush, 1995. Downstream ecological effects of dams, *Bioscience*, Vol. 45, No. 3., pp. 183-192.

McBain and Trush, 1997. *Trinity River Maintenance Flow Study - Final Report*, Arcata, California.

M.G. Wolman and L.B. Leopold, 1957. River Flood Plains: Some observations on their formation, *USGS Professional Paper 282-C*, pp. 87-107.

Olsen, H.O. (ed) 1996. River Restoration -- Danish experience and examples. National Environmental Research Institute. Silkeborg, Denmark.

Parker, G., P. C. Klingeman, et al., 1982. Bedload and size distribution in paved gravel-bed streams, *Journal of the Hydraulics Division*, Vol. 108, No. HY4, pp. 544-571.

Parker, G., 1990. Surface-based bedload transport relation for gravel rivers, *Journal of Hydraulic Research,* Vol. 28, No. 4, pp. 417-436.

Toth, L.A., 1996. Restoring the hydrogeomorphology of the channelized Kissimmee River. In: Brookes, A. and Shields, F.D., Jr. *River Channel Restoration, Guiding Principles for Sustainable Projects*, John Wiley & Sons, Chichester, United Kingdom, pp. 369-383.

Pelzman, R. J., 1973. *Causes and Possible Prevention of Riparian Plant Encroachment on Anadromous Fish Habitat.* Environmental Services Branch, California Department of Fish and Game**:** 26 pp.

Sawyer, J. O. and T. Keeler-Wolf, 1995. *A Manual of California Vegetation.* California Native Plant Society, Sacramento.

The Nature Conservancy, 1998. *Sacramento River project: Riparian forest restoration manual*. Sacramento, California.

Williams, G. P., and M.G. Wolman, 1984. Downstream effects of dams on alluvial rivers, *USGS Professional Paper 1286*, 83p.

Williams, G.P., 1986. River Meanders and Channel Size, *Journal of Hydrology*, Vol. 88, p. 147-164.